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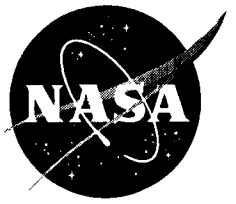

Recovery After Prolonged Bed-Rest Deconditioning

John E. Greenleaf and David T. Quach

January 2003

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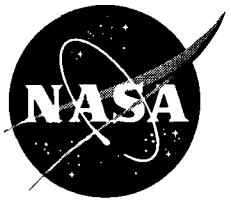

Recovery After Prolonged Bed-Rest Deconditioning

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RECOVERY AFTER PROLONGED BED-REST DECONDITIONING

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SUMMARY

Recovery data were analyzed from normal, healthy test subjects maintained in the horizontal or head-down body position in well-controlled bed rest (BR) studies in which adherence to the well-designed protocol was monitored. Because recovery data were almost always of secondary importance to the data collected during the BR period, there was little consistency in the recovery experimental designs regarding control factors (e.g., diet or exercise), duration, or timing of data collection. Thus, only about half of the BR studies that provided appropriate data were analyzed here. These recovery data were sorted into two groups: those from BR protocols of less than 37 days, and those from protocols greater than 36 days. There was great disparity in the unchanged responses at the end of BR in these two groups. Likewise with the variables that required more than 40 days for recovery; for example, some immune variables required more than 180 days. Knowledge of the recovery process after BR in healthy people should assist rehabilitation workers in differentiating "healthy" BR recovery responses from those of the infirmity of sick or injured patients; this should result in more appropriate and efficient health care.

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INTRODUCTION

Prolonged bed rest (BR >24 hr) has been prescribed by physicians, at least from the time of Hippocrates (450 B.C.), to facilitate healing and rehabilitation of their patients. Hippocrates recognized some harmful effects of prolonged rest, especially loss of muscular strength and tooth (bone) demineralization (Chadwick and Mann, 1950). Prolonged assumption of the horizontal body position reduces musculo-skeletal and orthostatic stress, facilitates cerebral perfusion, and usually lowers total body energy utilization in the sick and injured so that metabolic reserves utilized for maintaining upright posture and muscular activity can be directed to those needed by the immune system for recovery.

However, neuroendocrine-immune homeostatic control mechanisms are reset during prolonged BR in response to stimuli from (1) virtual elimination of hydrostatic pressure within the cardiovascular-lymph system on vessels below the heart, and increased pressure on vessels above the heart, including the brain and vestibular organs; (2) reduced skeletal muscle force (torque) on bones from muscle atrophy associated with decreased body energy expenditure and body water volume; and (3) some adverse psychophysiological responses during the novel and sometimes stressful environment of partial confinement in bed and the accompanying hospital routine. The latter includes changes in the physical environment, and food and fluid selection associated with constipation and difficulty with bowel movements which may or may not alter taste sensitivity and attenuate appetite (Sorokin et al., 1969; Vickers et al., 2001). The integrated adaptive responses from these and other interactive stimuli constitute major factors contributing to the BR-deconditioning syndrome.

Deconditioning is defined as "1: to cause to lose fitness < prolonged inactivity deconditions a person physically >" (Gove, 1986). This "adaptive" homeostatic condition is optimal for survival during BR as long as the gravitational vector remains perpendicular to the long axis of the body (i.e., from the chest to the back). It is the rather abrupt change from the horizontal (or weightless) condition to the upright sitting or standing postures, where the gravitational vector is from head-to-foot, that activates the "adverse" adaptive physiological signs and symptoms of the deconditioning. It is clear this adaptive-homeostatic-deconditioning syndrome occurs simultaneously to some degree in patients bed-rested by physicians to facilitate healing and rehabilitation, and that it is induced in healthy subjects for study by scientists of this "undesirable" syndrome and to devise countermeasures. Hence, the practical question is whether prolonged BR is helpful or harmful for patient recovery and rehabilitation (Ehrlich et al., 1994; Heaman and Gupton, 1998; Siebens et al., 2000).

Until the ramifications of this treatment are fully elucidated, prolonged BR should be prescribed or modified judiciously (Bassey and Fentem, 1974). A classic definition of rehabilitation "b: the physical restoration of a sick or disabled person by therapeutic measures and of his physical disability.... d: the restoration of something damaged or deteriorated to a prior good condition...." (Gove, 1986). This definition could be expanded to encompass this reverse homeostatic-adaptive-reconditioning process during recovery.

Results from a symposium chaired by Harrison (1944) in Chicago on the abuse of rest in the treatment of disease, and Asher's (1947) aphorism—"Teach us to live that we may dread unnecessary time in bed, get people up and we may save our patients from an early grave"—set the stage for an upsurge of BR studies (Fortney et al., 1996). A few studies were conducted before 1940, but the primary interest was academic, not practical medical applications. The

number of studies concerned with medical applications of BR data increased during and immediately following World War II but, in published studies, there appeared to be only minor interest in the physiology and time course of the ambulatory recovery process. By 1979 there had been well over 1,000 European, Soviet, and United States BR studies (Sheehan et al., 1979). The physiological and psychological aspects of prolonged BR deconditioning have been studied intensively (Greenleaf et al., 1976; Greenleaf and Kozlowski, 1982; Luu et al., 1990; Sheehan et al., 1979) and a few of them have been reviewed in some depth (Fortney et al., 1996; Greenleaf 1989, 1997; Greenleaf and Kozlowski, 1982; Greenleaf and Norsk, 1996; Greenleaf et al., 1994; Gretebeck and Greenleaf, 2000). In essentially all BR studies, the recovery data were of secondary importance to the primary data obtained before BR (in the control period) and during recumbency.

Thus, most ambulatory recovery data had to be gleaned from its secondary status when control elements of the BR phase (e.g., diet, exercise) had usually been removed. Nonetheless, important findings were extracted and analyzed. A better understanding of the post-BR recovery process in healthy subjects could provide baseline data with which to compare recovery data from hospitalized patients. This report presents graphic displays of recovery times for the major physiological and psychological systems following shorter-term (<37 days) and longer-term (>36 days) BR deconditioning in order to serve as a basis for an in-depth review of the recovery process.

METHODS

Recovery data were analyzed only from normal, healthy test subjects in well-controlled studies in which adherence to the BR protocol was monitored. There was no differentiation between the horizontal or head-down body positions of the subjects. Bed-rest experimental designs utilized the horizontal (0°) body position prior to 1972 when Voskresenskiy et al. published data from a 30-day study comparing the 0° position with the -4° head-down position. The head-down position (usually by 6°) was employed in most BR studies after 1980 (Greenleaf et al., 1982; Luu et al., 1990; Sheehan et al., 1979). The experimental designs of the studies by Taylor et al. and Saltin et al.— which deviated from the usual design—consisted of an ambulatory control period with no countermeasures, sometimes countermeasures during BR, and no countermeasures during ambulatory recovery. Taylor et al. (1949) studied six men who underwent a 6-week period of physical fitness training before BR, then 21 days of 0° BR with no countermeasures followed by a 6-week physical conditioning regimen during normal, ambulatory recovery. In the second, Saltin et al. (1968) bed-rested five men (0°) for 20 days without countermeasures and then exercise-trained them for 55 days during ambulatory recovery.

Data collected during the recovery periods after BR were almost always of secondary importance to those obtained from the pre-control and BR periods. As a result, there was essentially no consistency in recovery experimental designs in regard to duration, control factors, or timing of data collection. Therefore, our guidelines utilized for rejecting data were (1) BR periods less than 5 days; (2) recovery periods less than 2 days; (3) test groups less than four subjects; (4) recovery period not specified; and (5) evidence of poor or inadequate experimental design. Thus about half of the available BR studies that had recovery data are analyzed here. The recovery data were separated into two major groups: those obtained from BR studies of less

than 37 days, and those greater than 36 days. Each group was divided further into "No Countermeasures" and "Countermeasures" sections that were utilized or not during the BR period. The BR day on which data were collected was indicated; it was usually near the end of the BR period, but not necessarily at the end of the BR period. Data were taken directly from report figures or tables, and not from authors comments in the text. Some data interpretation was qualitative when statistical analyses were not provided. Data for each variable were qualitatively averaged or adjusted to obtain one point, a range, or a direction for recovery.

In the figures, a small square indicates a single day and a rectangle (elongated square) indicates the range. The black dot with an arrow pointing to the left indicates recovery earlier than the dot and an arrow pointing to the right indicates recovery later than the dot. Data in the far left column are the raw recovery values used to establish the rectangles or arrows. Abbreviations used in the figures are defined in the figures.

RESULTS: BED REST LESS THAN 37 DAYS

Anthropometry

Many anthropometric responses were likely influenced by changes in body weight which often decreased (DEC) during BR because of negative caloric balance. This was a result mainly, of insufficient intake, especially if subjects were exercising during BR (fig. 1, p. 1). Limb circumferences and volumes (except leg and thigh) were generally unchanged during BR. Calf and thigh muscle volumes decreased and required more than 30 days to recover—perhaps up to 55 days; but lean body mass recovered in less than 30 days whereas recovery of body fat content may require 55 days. Body total bone content was unchanged during BR less than 36 days (fig. 1, p. 2). Thus, decreases in body weight and lower extremity muscle volume and thickness required the longer times for recovery after BR of less than 36 days.

Physiological Systems

Cardiovascular variables. Basal and resting heart rates were either unchanged (UNC) or increased (INC) during BR with recovery in fewer than 60 days (fig. 1, p. 4). The decrease in heart volume and stroke volume also recovered in 3-60 days. Cerebral vascular functions were unchanged (fig. 1, p. 5). The various blood pressures inhibited variable responses during BR, with resting SBP and end-diastolic volume recovering in less than 30 days; the decrease in left-ventricular diastolic volume recovered in 3-62 days (fig. 1, p. 6). Cardiac index (CO/BSA in m^2) and right heart blood volume were unchanged, cardiac output increased and the decrease in stroke index, ejection fraction, femoral vascular resistance, central venous pressure, pulmonary arterial resistance, myocardial oxygen consumption, and coronary sinus blood flow and pressure required more than 2-10 days to recover. The decreased occlusive forearm and calf blood flows recovered by 30 days; limb venous compliance recovered beyond 2-7 days and limb pulse-wave velocities were generally unchanged (fig. 1, p. 7). Thus, many of the important cardiovascular variables that were disturbed during BR deconditioning do not recover promptly during reambulation.

Respiratory variables. All of the standard respiratory variables measured (except the increased oxygen and carbon dioxide alveolar-arterial gradients) required significant (>4 < 30 days) recovery periods (fig. 1, p. 9). Exercise training during BR shortened the 4-10 days recovery period of the decreased basal respiratory rate to about 1 day.

Blood-fluid hormonal variables. Because of its major importance in the totality of BR-deconditioning homeostasis, body fluid variables (and their recovery) have been studied extensively (fig. 1, p. 10). The characteristic decrease in plasma and blood volumes recovered between 2 and 30 days, and the hypervolemic effect of aerobic exercise training during BR can reduce recovery to 0-6 days. The decrease in red cell mass, volume, and total hemoglobin recovered in 6-30 days. The increased hematocrit and hemoglobin concentration recovered in 2-14 days (fig. 1, p. 11). The decrease in total body water content recovered by 7 days, but extracellular volume (plasma plus interstitial volumes) required more than 7 days, and intracellular volume was unchanged. It seems that cellular integrity (volume) follows the axiom that it is protected at the expense of the extracellular volume. Decreased glucose tolerance recovered within 7-14 days (fig. 1, p. 12). Plasma (and serum) sodium, potassium, calcium and osmotic concentrations remained unchanged with the decrease in plasma volume; the decrease in sodium and potassium balances recovered within 7 days (fig. 1, p. 13). Resting plasma vaso-active hormone concentrations were mostly unchanged or recovered beyond 3 days, whereas the decreased catecholamines recovered beyond 6 days (fig. 1, p. 14).

Cellular, enzyme variables. Many cells and cellular responses required more than 155 days to recover; the responsiveness of T and B lymphocyte; neutrophils, essinophils, suppressor/ cytotoxic cells ($CD8^+$), and concanavalin A was essentially unchanged (fig. 1, p. 16). Some lymphocyte reactivities recovered in less than 3 days but others required more than 3 days.

Urinary-renal variables. When urinary volume increased or decreased during BR, the recovery—which was unaffected by exercise—required up to 18 days (fig. 1, p. 20). Increased urinary sodium, chloride, phosphorus, and calcium recovered in 7-10 days. Urinary pH, creatinine, urea nitrogen, atrial natriuretic peptide, aldosterone, cortisol, citrate, sulfate, oxalate, and glomerular filtration rate were all essentially unchanged after fewer than 36 days of BR. Increased urinary total nitrogen, phosphate, glucose, epinephrine, norepinephrine, and renal vascular resistance recovered beyond 7 days; urinary magnesium and 17-OH steroids recovered in fewer than 7 days (fig. 1, p. 22).

Physiological Tests

Only basal oral temperature, submaximal SBP, and low-level (+2.1 G_z) acceleration tolerance were unchanged after fewer than 14 days of BR (fig. 1, p. 24). The decreased resting metabolism (oxygen uptake) recovered beyond 2 days. Decreased treadmill and ergometer endurance had recovered before 35 days. Uniformly decreased maximal oxygen uptake recovered between 25 and 62 days. Decreased maximal anaerobic threshold recovered before 14 days, and increased maximal exercise heart rate recovered by 30 days. Decreased orthostatic and $+G_z$ acceleration tolerances recovered between 3 days and beyond 20 days with no appreciable effect of exercise training during BR (fig. 1, p. 26). Most decreased maximal

voluntary muscular contractions recovered before 30 days; right knee and elbow flexion and plantar flexion recovered beyond 30 days (fig. 1, p. 27).

Psychological Tests

Contrary to the results of the physiological tests, many psychological tests including perceptive speed, slow nystagmus phase velocity, nystagmus frequency, perceptual speed, speed of closure, math, memory, fatigue scale, critical tracking, matrix and the Manikin test, were unchanged during BR (fig. 1, pp. 29, 30). The increase in aiming test and flexibility of closure and decrease in dual tracking required 6-16 days for recovery. Decreased taste sensitivity recovered before 7 days.

RESULTS: BED REST GREATER THAN 36 DAYS

Anthropometry

Changes (both increases and decreases) in most body segments recovered in fewer than 14 days. The exceptions were weights of the thigh and middle trunk, and circumferences of the middle trunk, lower trunk, and calf, which recovered beyond 11-14 days (fig. 2, p. 1). Essentially all increased skin folds (indicating increased fat and possibly water content) recovered by 14 days. Some soleus muscle fiber parameters, including the number of myonuclei, most fiber types, and cross-sectional area, were unchanged; decreases in total cytoplasmic volume and various fiber cross-sectional area recovered beyond 40 days. The decrease in total body bone mineral content was recovered between 70 and 180 days (fig. 2, p. 4). But the mineral content of some bones was unchanged: arms, proximal and distal radii, proximal and distal ulnae, ribs, and thoracic spine. Loss of mineral content that occurred in the trunk, pelvis, and calcaneous required more than 180 days for recovery; that in the tibia and fibula recovered beyond 30 days (fig. 2, p. 5).

Physiological Systems

Cardiovascular variables. The increased resting heart rate recovered in 14-30 days; most other heart variables were either unchanged or required 8-50 days for recovery (fig. 2, pp. 6, 7). While the ear-canal temperature was essentially unchanged, its decreased circadian amplitude recovered beyond 20 days (fig. 2, pp. 8, 9). General body thermoregulation recovered at about 30 days.

Respiratory variables. Unchanged respiratory variables were lung diffusion membrane and capillary capacity, peak expiratory flow, forced expiratory volume, and functional residual capacity; the increased alveolar pO_2, alveolar-arterial O_2 gradient, and decreased forced expiratory volume, forced vital capacity, and CO diffusing capacity recovered beyond 7-15 days (fig. 2, pp. 10, 11).

Blood-fluid hormonal variables. Blood and plasma volumes and total body water recovered in fewer than 12-20 days; red cell mass recovered beyond 20 days (fig. 2, p. 12). Serum electrolytes (except magnesium and calcium) recovered in fewer than 14 days. Plasma insulin and glucose levels recovered within 10-20 days (fig. 2, p. 14).

Cellular, enzyme variables. Serum total protein and various globulins recovered in 7-30 days; alkaline phosphate and osteocalcin took more than 40 days (fig. 2, p. 15). Most dehydrogenases and phosphatases recovered beyond 7 days. Plasma amino acids are either unchanged (cystine, aspartic acid, glutamic acid, proline) or recovered after 14 days (fig. 2, pp. 16, 17). Plasma triiodothyronine, thyroxine, and prolactin were unchanged; adreno-corticotrophic and growth hormones recovered after 20 days (fig. 2, p. 18). Most T-lymphocyte cells and natural killer cell activity and white cell lyphocytes and monocytes were unchanged (fig. 2, p. 19). The lipases recovered after 10 days.

Urinary-renal variables. Only urinary calcitonin, fecal phosphorus, and creatinine clearance were unchanged (fig. 2, pp. 21, 22). Urinary nitrogen, potassium, phosphorous, calcium, pyridinium cross-links, and deoxypyridinium and fecal calcium recovered beyond 28 days.

Physiological Tests

Maximal work parameters (O_2 uptake, endurance, heart rate) take longer than 2 days to recover; the step-test parameters and general body fatigue recovered in 30-70 days (fig. 2, p. 23). Orthostatic and acceleration tolerance generally required 17-50 days for recovery. The generally decreased muscular forces and strengths recovered between 10-20 days (fig. 2, p. 24).

Psychological Tests

Most body posture equilibrium and gait parameters (including foot sensitivity) recovered beyond 14 days (fig. 2, pp. 25, 26).

SUMMARY OF RESULTS

Figures 1 and 2 present relatively clean data from about half of the BR studies (those with well-controlled experimental designs) that contained recovery information. An a priori hypothesis would be that changes in variables after prolonged (>36 days) BR would be somewhat different from those with BR less than 37 days; and that recovery of variables after longer-term BR would be essentially similar (perhaps somewhat longer) to that of variables after the shorter-term BR. The general observation is that recovery is only somewhat longer with BR greater than 36 days. This would be expected if an equilibrium had not been reached in a variable before 36 days. However, many immune cell responses required more than 155 days for recovery during BR less than 37 days, and some bone parameters, as well as general body fatigue, recovered near and beyond 180 days during BR greater than 36 days.

A summary of responses at each end of the recovery spectrum, that is, those unchanged at the end of BR versus those with extended recovery (greater than 40 days), revealed unexpectedly heterogeneous responses. With BR less than 37 days, variables unchanged at the end of BR included the following:

1. Limb and body section circumferences and volumes
2. Many blood vessel pressures and cardiac parameters
3. Some plasma electrolytes
4. Some blood immune cells
5. Many cognitive and psychomotor responses

These can be compared with those unchanged variables during BR greater than 36 days, which included the following:

1. Some soleus fiber types
2. Bone mineral in arm bones, ribs, and thoracic spine
3. Heart rate and volume and some pulse wave velocities
4. Lung diffusion and flow
5. Serum calcium, phosphorus, albumin, and globulin concentrations
6. Some plasma amino acids
7. Some blood immune cells
8. Urinary calcitonin and creatinine clearance

Long-term recovery (>40 days) of variables following BR less than 37 days include the following:

1. Intervertebral disc size and area
2. Bone mineral in trunk, pelvis, and calcaneus
3. Serum alkaline phosphate, osteocalcin
4. Blood $CD4^+$, $CD8^+$, and $CD56^+$ cells
5. Urinary pyridinium crosslinks and deoxypyridinium
6. Step test recovery and general body fatigue
7. +Gx acceleration tolerance

These can be compared with recovery of those variables following BR greater than 36 days which include the following:

1. Body fat content
2. Hemoglobin concentration and white blood cells
3. Some blood cells including segmented neutrophils, basophils, $CD3^+$, $CD4^+$, $CD19^+$, NK cells, and HLA-lymphocytes
4. Maximal oxygen uptake
5. Muscular strength of the hand grip, plantar flexion, knee flexion and extension, and elbow flexion

There is no regular pattern in the response of variables after shorter- and longer-term BR nor in long-term (>40 days) recovery with data from these selected studies. Some variables had not recovered by 180 days. Clearly, total body physiological equilibrium is reached sometime during continuous BR as exemplified by the case of a man, Jonnie Richardson, who went to bed in 1932 at age 16 in an isolated mountain cabin near Laurel Springs, North Carolina, and lived

for at least 50 more years. At age 66 he was described as "a ghost of a mountain man, a lily-white frame with limbs as thin as the legs of a ladder-back chair" (San Jose Mercury).

Prolonged stay in recovery and rehabilitation facilities is very expensive, hence the stimulus for early ambulation. But how can the care-provider determine when recovery is sufficient? The extended recovery time of some immune cellular processes could increase the possibility of further disease or injury. Because most of the recovery data after prolonged BR are descriptive, solid, hypothesis-driven research into the mechanisms of the recovery process is urgently needed.

REFERENCES

Arbeille, Ph., G. Gauquelin, J.M. Pottier, L. Pourcelot, A. Güell, and C. Gharib. Results of a 4-week head-down tilt with and without LBNP countermeasure: II. Cardiac and peripheral hemodynamics—comparison with a 25-day spaceflight. Aviat. Space Environ. Med. 63:9-13, 1992.

Arnaud, S.B., D.J. Sherrard, N. Maloney, R.T. Whalen, and P. Fung. Effects of 1-week head-down tilt bed rest on bone formation and the calcium endocrine system. Aviat. Space Environ. Med. 63:14-20, 1992.

Artamonova, N.P., T.S. Zakharova, B.V. Morukov, G.S. Arzamazov, and V.Yu. Semenov. Bioelectrical activity of the heart and blood electrolytes in essentially healthy subjects submitted to antiorthostatic hypokinesia for 120 days. Kosm. Biol. Aviakosm. Med. 20:24-27, 1986.

Asher, R.A.J. The dangers of going to bed. Br. Med. J. 4:967-968, 1947.

Aust, G., H. Denz, and F. Baisch. Inner ear characteristics during 7 day antiorthostatic bedrest (6° head down tilt). In: Proc. 2nd Europ. Symp. Life Sci. Res. Space. ESA SP-212:251-255, 1984.

Aust, G., A. Putzka, and F. Baisch. Effects of head down tilt (HDT) fluid volume shift on cerebral sensory responses. In: Proc. 35th Cong. Int. Astro. Fed. IAF-84-191:1-5, 1984.

Baisch, F., L. Beck, E.W. Müller, and A. Samel. Cardiocirculatory adjustment during a 7-day microgravity simulation (6° head-down tilt (HDT)). In: Proc. 35th Cong. Int. Astro. Fed. IAF-84-187:1-5, 1984.

Bassey, E.J., and P.H. Fentem. Extent of deterioration in physical condition during postoperative bed rest and its reversal by rehabilitation. Br. Med. J. 4:194-196, 1974.

Beckett, W.S., N.B. Vroman, D. Nigro, S. Thompson-Gorman, J.E. Wilkerson, and S.M. Fortney. Effect of prolonged bed rest on lung volume in normal individuals. J. Appl. Physiol. 61:919-925, 1986.

Belaya, N.A., R.Z. Amirov, Ye.A. Shaposhnikov, I.P. Lebedeva, and B.S. Sologub. Some features of the bioelectric activity of the muscles with prolonged hypokinesia. Vop. Kurortol. Fizioterap. Lech. Fizich. Kult. 40: 238-241, 1975.

Beregovkin, A.V., P.V. Buyanov, A.V. Galkin, N.V. Pisarenko, and Ye.Ye. Sheludyakov. Results of investigations of the cardiovascular system during the aftereffect of 70-day hypodynamia. Prob. Kosm. Biol. 13:221-227, 1969.

Bonde-Petersen, F., A. Guell, K. Skagen, and O. Henriksen. The effect of clonidine on peripheral vasomotor reactions during simulated zero gravity. Physiologist 24:S-89-S-90, 1981.

Brannon, E.W., C.A. Rockwood, Jr., and P. Potts. The influence of specific exercises in the prevention of debilitating musculoskeletal disorders; implication in physiological conditioning for prolonged weightlessness. Aerospace Med. 34:900-906, 1963.

Buckey, J.C., L.D. Lane, G. Plath, F.A. Gaffney, F. Baisch, and C.G. Blomqvist. Effects of head-down tilt for 10 days on the compliance of the leg. Acta Physiol. Scand. 144:Suppl. 604:53-60, 1992.

Budylina, S.M., V.A. Khvatova, and A.I. Volozhin. Effect of orthostatic and antiorthostatic hypokinesia on human taste sensitivity. Kosm. Biol. Aviakosm. Med. 10:27-30, 1976.

Chadwick, J., and W.N. Mann. The Medical Works of Hippocrates. Oxford: Blackwell Scientific Publications, 1950. 301p.

Cherepakhin, M.A. Effect of prolonged bedrest on muscle tone and proprioceptive reflexes in man. Kosm. Biol. Med. 2:43-47, 1968.

Chernukh, A.M., O.G. Gazenko, B.M. Fedorov, T.N. Krupina, P.N. Aleksandrov, D.I. Shagal, N.Ye. Panferova, and T.M. Proskurina. Effect of hypokinesia on blood microcirculation. Pathologich. Fiziol. Eksper. Terap. 9:10-13, 1979.

Convertino, V.A., C.R. Kirby, G.M. Karst, and D.J. Goldwater. Response to muscular exercise following repeated simulated weightlessness. Aviat. Space Environ. Med. 56:540-546, 1985.

Criswell, B.S., and S.L. Kimzey. The influence of bedrest on the lymphocytic response of man. Aerospace Med. Assoc. Preprints: 191-192, 1977.

DeBusk, R.F., V.A. Convertino, J. Hung, and D. Goldwater. Exercise conditioning in middle-aged men after 10 days of bed rest. Circulation 68:245-250, 1983.

Deitrick, J.E., G.D. Whedon, E. Shorr, V. Toscani, and V.B. Davis. Effects of immobilization upon various metabolic and physiologic functions of normal men. Am. J. Med. 4:3-36, 1948.

Dolkas, C.B., and J.E. Greenleaf. Insulin and glucose responses during bed rest with isotonic and isometric exercise. J. Appl. Physiol. 43:1033-1038, 1977.

Donaldson, C.L., et al. The effect of prolonged simulated non-gravitational environment on mineral balance in the adult male. Washington, DC: NASA Contractor Rept. 108314, Vol. 1, 1969. 91p.

Donaldson, C.L., S.B. Hulley, J.M. Vogel, R.S. Hattner, J.H. Bayers, and D.E. McMillan. Effect of prolonged bed rest on bone mineral. Metabolism 19:1071-1084, 1970.

Drozdova, N.T., and O.N. Nesterenko. State of the visual analyzer during hypodynamia. Prob. Kosm. Biol. 13:189-191, 1969.

Dudley, G.A., M.R. Duvoisin, V.A. Convertino, and P. Buchanan. Alterations of the in vivo torque-velocity relationship of human skeletal muscle following 30 days exposure to simulated microgravity. Aviat. Space Environ. Med. 60:659-663, 1989.

Ehrlich, F., R.G. Poulos, C.J. Poulos, B. Burraston, S. Lord, and R. Salgado. Bed rest in a Sydney teaching hospital. Arch. Gerontol. Geriatr. Suppl. 4:39-44, 1994.

Ellis, S., L.C. Kirby, and J.E. Greenleaf. Lower extremity muscle thickness during 30-day 6° head-down bed rest with isotonic and isokinetic exercise training. Aviat. Space Environ. Med. 64:1011-1015, 1993.

Fortney, S.M., K.H. Hyatt, J.E. Davis, and J.M. Vogel. Changes in body fluid compartments during a 28-day bed rest. Aviat. Space Environ. Med. 62:97-104, 1991.

Fortney, S.M., V.S. Schneider, J.E. Greenleaf. The physiology of bed rest. In: Handbook of Physiology: Section 4: Environmental Physiology. III. The gravitational environment, edited by M.J. Fregly, and C.M. Blatteis. New York: Oxford University Press. Vol. 2, Chapt. 39, 1996. pp. 889-939.

Fasola, A.F., and J.H. Triebwasser. The renin response to lower body negative pressure stress testing and the effect of exercise during prolonged bedrest. Aerospace Med. Assoc. Preprints: 63-64, 1970.

Friman, G. Effect of clinical bed rest for seven days on physical performance. Acta Med. Scand. 205:389-393, 1979.

Friman, G., and E. Hamrin. Changes of reactive hyperaemia after clinical bed rest for seven days. Upsala Med. Sci. 81:79-83, 1976.

Funato, K., A. Matsuo, H. Yata, H. Akima, Y. Suzuki, A. Gunji, and T. Fukunaga. Changes in force—velocity and power output of upper and lower extremity musculature in young subjects following 20 days of bed rest. J. Gravit. Physiol. 4:S22-S30, 1997.

Gauquelin, G., A. Maillet, A.-M. Allevard, D. Sigaudo, and C. Gharib. Diurnal rhythms of plasma renin activity, atrial natriurectic peptide and arterial pressure during head-down bed rest in humans. Eur. J. Appl. Physiol. 73:536-543, 1996.

Georgievskii, V.S., L.I. Kakurin, B.S. Katovskii, and Yu.A. Senkevich. Maximum oxygen consumption and functional state of the circulation in simulated zero gravity. In: The Oxygen Regime of the Organism and its Regulation, edited by N.V. Laurer and A.Z. Kolchinskaya. Kiev: Naukova Dumka, 1966. pp. 181-184.

Gmünder, F.K., F. Baisch, B. Bechler, A. Cogoli, M. Cogoli, P.W. Joller, H. Maass, J. Müller, and W.H. Ziegler. Effect of head-down tilt bedrest (10 days) on lymphocyte reactivity. Acta Physiol. Scand. 144:Suppl. 604:131-141, 1992.

Gove, P.B. (ed.) Webster's Third New International Dictionary of the English Language Unabridged. Springfield, MA: Merriam-Webster Inc., Publishers, 1986.

Greenleaf, J.E. Energy and thermal regulation during bed rest and spaceflight. J. Appl. Physiol. 67:507-516, 1989.

Greenleaf, J.E. Exercise thermoregulation with bed rest, confinement, and immersion deconditioning. Ann. N.Y. Acad. Sci. 813:741-750, 1997.

Greenleaf, J.E., E.M. Bernauer, L.T. Juhos, H.L. Young, J.T. Morse, and R.W. Staley. Effects of exercise on fluid exhange and body composition in man during 14-day bed rest. J. Appl. Physiol. 43:126-132, 1977.

Greenleaf, J.E., E.M. Bernauer, H.L. Young, J.T. Morse, R.W. Staley, L.T. Juhos, and W. Van Beaumont. Fluid and electrolyte shifts during bed rest with isometric and isotonic exercise. J. Appl. Physiol. 42:59-66, 1977.

Greenleaf, J.E., C.J. Greenleaf, D. Van Derveer, and K.J. Dorchak. Adaptation to prolonged bedrest in man: A compendium of research. Washington, DC: NASA Tech. Memo. X-3307, 1976. 180p.

Greenleaf, J.E., R.F. Haines, E.M. Bernauer, J.T. Morse, H. Sandler, R. Armbruster, L. Sagan, and W. Van Beaumont. $+G_z$ tolerance in man after 14-day bedrest periods with isometric and isotonic exercise conditioning. Aviat. Space Environ. Med. 46: 671-678, 1975.

Greenleaf, J.E., C.G.R. Jackson, and D. Lawless. CD4+/CD8+ T-lymphocyte ratio: effects of rehydration before exercise in dehydrated men. Med. Sci. Sports Exerc. 27:194-199, 1995.

Greenleaf, J.E., L.T. Juhos, and H.L. Young. Plasma lactic dehydrogenase activities in men during bed rest with exercise training. Aviat. Space Environ. Med. 56:193-198, 1985.

Greenleaf, J.E. Physiological consequences of reduced physical activity during bed rest. In: Exercise and Sport Sciences Reviews, edited by R.L. Terjung. Philadelphia, PA: Franklin Institute Press, 10:84-119, 1982.

Greenleaf, J.E., and P. Norsk. Mechanism for cardiovascular and body fluid adjustments during bed rest and space flight. In: Physiological Basis of Occupation Health: Stressful Environments, edited by K. Shiraki, S. Sagawa, and M.K. Yousef. Amsterdam: SPB Academic Publishing bv, 1996. p. 97-114.

Greenleaf, J.E., L. Silverstein, J. Bliss, V. Langenheim, H. Rossow, and C. Chao. Physiological responses to prolonged bed rest and fluid immersion in man: A compendium of research (1974-1980). Moffett Field, CA: NASA Tech. Memo. 81324, 1982. 110p.

Greenleaf, J.E., H.O. Stinnett, G.L. Davis, J. Kollias, and E.M. Bernauer. Fluid and electrolyte shifts in women during $+G_z$ acceleration after 15 days' bed rest. J. Appl. Physiol. 42: 67-73, 1977.

Greenleaf, J.E., W. Van Beaumont, E.M. Bernauer, R.F. Haines, H. Sandler, R.W. Staley, H.L. Young, and J.W. Yusken. Effects of rehydration on $+G_z$ tolerance after 14-days' bed rest. Aerospace Med. 44:715-722, 1973.

Gretebeck, R.J., and J.E. Greenleaf. Utility of ground-based simulations of weightlessness. In: Nutrition in Spaceflight and Weightlessness Models, edited by H.W. Lane, and D.A. Schoeller. Boca Raton, FL: CRC Press, 2000. pp. 69-96.

Grigoriev, A.I., V.S. Oganov, A.S. Rakhmanov, and B.V. Morukov. Bone examination by noninvasive techniques in a 120-day head-down tilt test. In: Proc. 2nd Int. Conf. Space Physiol. ESA SP-237, 1985. pp. 99-103.

Grigor'yev, A.I., B.R. Dorokhova, G.I. Kozyrevskaya, Yu.V. Namochin, G.S. Arzamazov, and V.B. Noskov. Water-salt metabolism and the functional state of the kidneys during bedrest of varying duration. Fiziol. Cheloveka 5:660-669, 1979.

Guëll, A., C1. Gharib, G. Fanjaud, and A. Bes. Effects of antiorthostatic position at -4° on hydromineral balance. Physiologist 25:S71-S72, 1982.

Guëll, A., L. Pourcelot, J.L. Mauroux, Ph. Dupui, and A. Bès. Interest of head down tilt to simulate the neurocirculatory modifications observed during space flight. In: Proc. 35th Cong. Int. Astro. Fed. IAF-84-190, 1984. p. 1-4.

Gurfinkel', V.S., Ye.I. Pal'tsev, A.G. Fel'dman, and A.M. El'ner. Changes in certain human motor functions after prolonged hypodynamia. Prob. Kosm. Biol. 13:148-161, 1969.

Haines, R.F. Effect of bed rest and exercise on body balance. J. Appl. Physiol. 36:323-327, 1974.

Harrison, T.R. Abuse of rest as a therapeutic measure for patients with cardiovascular disease. JAMA 125:1075-1077, 1944.

Heaman, M., and A. Gupton. Perceptions of bed rest by women with high-risk pregnancies: A comparison between home and hospital. Birth 25:252-258, 1998.

Heer, M., C. Drummer, F. Baisch, H. Maass, R. Gerzer, J. Kropp, and C.G. Blomqvist. Effects of head-down tilt and saline loading on body weight, fluid, and electrolyte homeostasis in man. Acta Physiol. Scand. 144:Suppl. 604:13-22, 1992.

Hulley, S.B., J.M. Vogel, C.L. Donaldson, J.H. Bayers, R.J. Friedman, and S.N. Rosen. The effect of supplemental oral phosphate on the bone mineral changes during prolonged bed rest. J. Clin. Invest. 50:2506-2518, 1971.

Hwang, T.I.S., K. Hill, V. Schneider, and C.Y.C. Pak. Effect of prolonged bedrest on the propensity for renal stone formation. J. Clin. Endocrinol. Metab. 66:109-112, 1988.

Hyatt, K.H., L.B. Jacobson, and V.S. Schneider. Comparison of 70° tilt, LBNP, and passive standing as measures of orthostatic tolerance. Aviat. Space Environ. Med. 46:801-808, 1975.

Kakurin, L.I., B.B. Yegorov, Ye.I.Il'ina, and M.A. Cherepakhin. Effects of muscle electrostimulation during simulated weightlessness. Acta Astronautica 2:241-246, 1975.

Kalin, G.S., and V.G. Terent'yev. State of nervous-system functions during aftereffects of hypodynamia. Prob. Kosm. Biol. 13:214-220, 1969.

Kamiya, A., S. Iwase, H. Kitazawa, T. Mano, O.L. Vinogradova, and I.B. Kharchenko. Baroreflex control of muscle sympathetic nerve activity after 120 days of 6° head-down bed rest. Am. J. Physiol. Regulatory Integrative Comp. Physiol. 278:R445-R452, 2000.

Kashihara, H., Y. Haruna, Y. Suzuki, K. Kawakubo, K. Takenaka, F. Bonde-Peterson, and A. Gunji. Effects of mild supine exercise during 20 days bed rest on maximal oxygen uptake rate in young humans. Acta Physiol. Scand. 150:Suppl. 616:19-26, 1994.

Kas'yan, I.I., V.A. Talavrinov, V.I. Luk'yanchikov, and Ye. A. Kobzev. Effect of antiorthostatic hypokinesia and spaceflight factors on change in leg volume. Kosm. Biol. Aviakosm. Med. 14:51-55, 1980.

Katkov, V.E., V.V. Chestukhin, and L.I. Kakurin. Coronary circulation of the healthy man exposed to tilt tests, LBNP, and head-down tilt. Aviat. Space Environ. Med. 56:741-747, 1985.

Katkov, V.E., V.V. Chestukhin, E.M. Nikolayenko, V.V. Rumyantsev, and S.V. Gvozdev. Central circulation of a normal man during 7-day head-down tilt decompression of various body parts. Aviat. Space Environ. Med. Suppl. 54:Suppl. 1:S24-S30, 1983.

Katkovskiy, B.S., and Yu.D. Pometov. Change in cardiac ejection under the influence of 15-day bed confinement. Kosm. Biol. Med. 5:69-74, 1971.

Keil, L.C., and S. Ellis. Plasma vasopressin and renin activity in women exposed to bed rest and $+G_z$ acceleration. J. Appl. Physiol. 40:911-914, 1976.

Kimzey, S.L., J.I. Leonard, and P.C. Johnson. A mathematical and experimental simulation of the hematological response to weightlessness. Acta Astronautica 6:1289-1303, 1979.

Kiselev, R.K., I.S. Balakhovskiy, and O.A. Virovets. Change in hemoglobin mass during prolonged hypokinesia. Kosm. Biol. Aviakosm. Med. 9:80-84, 1975.

Korobkov, A.V., L.A. Ioffe, M.A. Abrikosova, and Yu.M. Stoyda. Dynamics of orthostatic tolerance of athletes after forty-day hypokinesia. Kosm. Biol. Med. 2:33-40, 1968.

Kotov, A.N. Diffusion capacity of the human lungs under the combined effect of hypokinesia and hypoxia. Kosm. Biol. Aviakosm. Med. 11:85-86, 1977.

Kotovskaya, A.R., R.A. Vartbaronov, and S.F. Simpura. Change in load-factor tolerance after 70 days of hypodynamia. Prob. Kosm. Biol. 13:241-247, 1969.

Kotovskaya, A.R., R.A. Vartbaronov, and S.F. Simpura. Change in the capacity of man to withstand transverse stresses after hypodynamia of varying duration. Prob. Kosm. Biol. 16:46-54, 1971.

Krasnykh, I.G. Influence of prolonged hypodynamia on heart size and the functional state of the myocardium. Prob. Kosm. Biol. 13:65-71, 1969a.

Krasnykh, I.G. Mineral saturation of bone tissue under conditions of prolonged hypodynamia. Prob. Kosm. Biol. 13:94-99, 1969b.

Krasnykh, I.G. Roentgenological examination of the human heart after 100-day hypokinesia. Kosm. Biol. Aviakosm. Med. 13:28-31, 1979.

Krotov, V.P, A.A. Titov, Ye.A. Kovalenko, V.V. Bogomolov, L.L. Stazhadze, and V.P. Masenko. Changes in fluid metabolism during prolonged hypokinesia with the body in antiorthostatic position. Kosm. Biol. Aviakosm. Med. 11:32-37, 1977.

Krupina, T.N., and A.Ya. Tizul. Clinical aspects of changes in the nervous system in the course of 49-day antiorthostatic hypokinesia. Kosm. Biol. Aviakosm. Med. 11:26-31, 1977.

Krupina, T.N., A.Ya. Tizul, N.M. Boglevskaya, B.P. Baranova, E.I. Matsnev, and Ye.A. Chertovskikh. Functional changes in the nervous system and functioning and certain analyzers in response to the combined effect of hypokinesia and radial acceleration. Kosm. Biol. Med. 1:61-66, 1967.

Krupina, T.N., A.Ya. Tizul, M.P. Kuz'min, and N.I. Tsyganova. Clinicophysiological changes in man during long-term antiorthostatic hypokinesia. Kosm. Biol. Aviakosm. Med. 16:29-34, 1982.

Lampe, L., K. Wienhold, G. Meyer, F. Baisch, H. Maass, W. Hollmann, and R. Rost. Effects of simulated microgravity (HDT) on blood fluidity. J. Appl. Physiol. 73:1366-1369, 1992.

LeBlanc, A.D., H.J. Evans, V.S. Schneider, R.E. Wendt III, and T.D. Hedrick. Changes in intervertebral disc cross-sectional area with bed rest and space flight. Spine 9:812-817, 1994.

LeBlanc, A.D., V.S. Schneider, H.J. Evans, D.A. Engelbretson, and J.M. Krebs. Bone mineral loss and recovery after 17 weeks of bed rest. J. Bone Miner. Res. 5:843-850, 1990.

LeBlanc, A., V. Schneider, E. Spector, H. Evans, R. Rowe, H. Lane, L. Demers, and A. Lipton. Calcium absorption, endogenous excretion, and endocrine changes during and after long-term bed rest. Bone 16:Suppl:301S-304S, 1995.

Louisy, F. P. Berry, J.F. Marinia, A. Guëll, and C.Y. Guezennec. Characteristics of the venous hemodynamics of the leg under simulated weightlessness: Effects of physical exercise as countermeasure. Aviat. Space Environ. Med. 66:542-549, 1995.

Lutwak, L., and G.D. Whedon. The effect of physical conditioning on glucose tolerance. Clin. Res. 7:143-144, 1959.

Luu, P.B., V. Ortiz, P.R. Barnes, and J.E. Greenleaf. Physiological responses to prolonged bed rest in humans: A compendium of research (1981-1988). Moffett Field, CA: NASA Tech. Memo. 102249, 1990. 134p.

Maass, H., J. Transmontano, and F. Baisch. Response of adrenergic receptors to 10 days head-down tilt bedrest. Acta Physiol. Scand. 144:Suppl. 604:61-68, 1992.

Maillet, A., G. Gauquelin, H.C. Gunga, J.O. Fortrat, K. Kirsch, A. Guell, Ch.A. Bizollon, and C. Gharib. Blood volume regulating hormones response during two space related simulation protocols: Four-week confinement and head-down bed-rest. Acta Astronautica 35:547-552, 1995.

Martin, D.G., V.A. Convertino, D. Goldwater, E.W. Ferguson, and E.B. Schoomaker. Plasma viscosity elevations with simulated weightlessness. Aviat. Space Environ. Med. 57:426-431, 1986.

McMillan, D.E., and C.L. Donaldson. Changes in serum proteins, viscosity, and protein-bound carbohydrates during prolonged bedrest. Aviat. Space Environ. Med. 46:132-135, 1975.

Medkova, I.L., N.M. Nikolayeva, and O.V. Zhiznevskaya. Lipid hydrolysis in man during antiorthostatic hypokinesia. Kosm. Biol. Aviakosm. Med. 19:40-44, 1985.

Mikhaylovskiy, G.P., T.V. Benevolenskaya, T.A. Petrova, I.Ya. Yakovleva, O.I. Boykova, M.P. Kuz'min, A.A. Savilov, and S.N. Solov'yeva. The combined effect of two-month hypokinesia and radial accelerations on the cardiovascular system. Kosm. Biol. Med. 1:57-60, 1967a.

Mikhaylovskiy, G.P., N.N. Dobronravova, M.I. Kozar', M.M. Korotayev, N.I. Tsiganova, V.M. Shilov, and I.Ya. Yakovleva. Variation in overall body tolerance during a 62-day exposure to hypokinesia and acceleration. Kosm. Biol. Med. 1:66-70, 1967b.

Miller, P.B., R.L. Johnson, and L.E. Lamb. Effects of four weeks of absolute bed rest on circulatory functions in men. Aerospace Med. 35:1194-1200, 1964.

Montgomery, L.D. Body volume changes during simulated weightlessness: An overview. Aviat. Space Environ. Med. 58:Suppl. 9:A80-A85, 1987.

Montmerle, S., J. Spaak, and D. Linnarsson. Lung function during and after prolonged head-down bed rest. J. Appl. Physiol. 92:75-83, 2002.

Morse, B.S. Erythrokinetic changes in man associated with bed rest. Clin. Res. 16:240-254, 1968.

Müller, E.W., H. Hohlweck, G. Plath, and F. Baisch. Leg volume changes. Responses to LBNP during 7 days of 0-G simulation (6° HDT). In: Proc. 2nd Europ. Symp. on Life Sci. Res. Space. ESA SP-212:159-162, 1984.

Narici, M.V., B. Kayser, P. Barattini, P. Cerretelli. Changes in electrically evoked skeletal muscle contractions during 17-day spaceflight and bed rest. Int. J. Sports Med. 18:S290-S292, 1997.

Newsom, B.D., W.L. Goldenrath, W.R. Winter, and H. Sandler. Tolerance of females to $+G_z$ centrifugation before and after bedrest. Aviat. Space Environ. Med. 48:327-331, 1977.

Noskov, V.B., G.I. Kozyrevskaya, B.V. Morukov, Ye.M. Artamasova, and L.A. Rustam'yan. Body position during hypokinesia, and fluid-electrolyte metabolism. Kosm. Biol. Aviakosm. Med. 19:31-34, 1985.

Ohira, Y., T. Yoshinaga, M. Ohara, I. Nonaka, T. Yoshioka, K. Yamashita-Goto, B.S. Shenkman, I.B. Kozlovskaya, R.R. Roy, and V.R. Edgerton. Myonuclear domain and myosin phenotype in human soleus after bed rest with or without loading. J. Appl. Physiol. 87:1776-1785, 1999.

Panferova, N.Ye. Vascular tone in different parts of the body during prolonged restriction of muscular activity. Kosm. Biol. Med. 6:47-50, 1972.

Panferova, N.Ye., and V.A. Tishler. Arterial tone in relation to restricted muscular activity. Kosm. Biol. Med. 2:56-61, 1968.
Parin, V.V., T.N. Krupina, G.P. Mikhaylovskiy, and A.Ya. Tizul. Principal changes in the healthy human body after a 120-day bed confinement. Kosm. Biol. Med. 4:59-64, 1970.

Pestov, I.D., M.I. Tishchenko, B.A. Korolev, B.F. Asyamolov, V.V. Simonenko, and A.Ye. Baykov. An investigation of orthostatic stability after prolonged hypodynamia. Prob. Kosm. Biol. 13:231-240, 1969.

Petukhov, B.N., and Yu.N. Purakhin. Effect of prolonged bedrest on cerebral biopotentials of healthy subjects. Kosm. Biol. Med. 2:56-61, 1968.

Polese, A., D. Goldwater, L. London, D. Yuster, and H. Sandler. Resting cardiovascular effects of horizontal (0°) and head-down (-6°) bed rest (BR) on normal men. Aerospace Med. Assoc. Preprints: 24-25, 1980.

Popova, I.A., B.V. Morukov, and A.S. Ushakov. Metabolic changes during prolonged antiorthostatic hypokinesia. In: Proc. 2nd Int. Conf. Space Physiol. ESA SP-237:167-172, 1985.

Purakhin, Yu.N., L.I. Kakurin, V.S. Georgiyevskiy, B.N. Petukhov, and V.M. Mikhaylov. Regulation of vertical posture after flight on the 'Soyuz-6'-'Soyuz-8' ships and 120-day hypokinesia. Kosm. Biol. Med. 6:47-53, 1972.

Ritz, P.A. Maillet, S. Blanc, R.J. Stubbs. Observations in energy and macronutrient intake during prolonged bed-rest in a head-down tilt position. Clin. Nutr. 18:203-207, 1999.

Ryback, R.S., R.W. Trimble, O.F. Lewis, and C.L. Jennings. Psychobiologic effects of prolonged weightlessness (bed rest) in young healthy volunteers. Aerospace Med. 42:408-415, 1971.

Saltin, B., G. Blomqvist, J.H. Mitchell, R.L. Johnson, Jr., K.Wildenthal, and C.B. Chapman. Response to exercise after bed rest and after training. Circulation 38:Suppl.7:1-78, 1968.

Sandler, H., P. Webb, J. Annis, N. Pace, B.W. Grunbaum, D. Dolkas, and B. Newsom. Evaluation of a reverse gradient garment for prevention of bed-rest deconditioning. Aviat. Space Environ. Med. 54:191-201, 1983.

Schmitt, D.A., L. Schaffar, G.R. Taylor, K.C. Loftin, V.S. Schneider, A. Koebel, M. Abbal, G. Sonnenfeld, D.E. Lewis, J.R. Reuben, and R. Ferebee. Use of bed rest and head-down tilt to simulate spaceflight-induced immune system changes. J. Interferon Cytokine Res. 16:151-157, 1996.

Schmitt, D.A., M. Schwarzenberg, J. Tkaczuk, S. Hebrard, G. Brandenberger, G. Mauco, M. Cogoli-Greuter, and M. Abbal. Head-down tilt bed rest and immune responses. Pflügers Arch. – Eur. J. Physiol. 441:Suppl:R79-R84, 2000.

Sheehan, B., J. McDivitt, and J. Jones. Chronological summaries of United States, European, and Soviet bedrest studies. Washington, DC: Office of Life Sciences:1-327, 1979.

Shebab, R.L., and R.E. Schlegel, and D.R. Eddy. The NASA performance assessment workstation: Cognitive performance during head-down bed rest. Acta Astronautica 43:223-233, 1998.

Shurygin, D.Ya, K.A. Sidorov, V.I. Mazurov, and N.M. Alekseyeva. The endocrine system in hypodynamia and readaptation. Voyenno-Med. 12:55-58, 1976.

Siebens, H., H. Aronow, D. Edwards, and Z. Ghasemi. A randomized controlled trial of exercise to improve outcomes of acute hospitalization in older adults. J. Am. Geriatr. Soc. 48:1545-1552, 2000.

Sigaudo, D., J.-O. Fortrat, A. Maillet, A.-M. Allevard, A.P. Traon, R.L. Hughson, A. Guëll, C. Gharib, and G. Gauquelin. Comparison of a 4-day confinement and head-down tilt on endocrine response and cardiovascular variability in humans. Eur. J. Appl. Physiol. 73:28-37, 1996.

Sorokin, P.A., V.V. Simonenko, and B.A. Korolev. Clinical observations in prolonged hypodynamia. Prob. Kosm. Biol. 13:24-34, 1969.

Stevens, P.M., P.B. Miller, C.A. Gilbert, T.N. Lynch, R.L. Johnson, and L.E. Lamb. Influence of long-term lower body negative pressure on the circulatory function of man during prolonged bed rest. Aerospace Med. 37:357-367, 1966.

Storm, W.F., and C.L. Giannetta. Effects of hypercapnia and bedrest on psychomotor performance. Aerospace Med. 45:431-433, 1974.

Stremel, R.W., V.A. Convertino, E.M. Bernauer, and J.E. Greenleaf. Cardiorespiratory deconditioning with static and dynamic leg exercise during bed rest. J. Appl. Physiol. 41:905-909, 1976.

Suzuki, Y., T. Murakami, Y. Haruna, K. Kawakubo, S. Goto, Y. Makita, S. Ikawa, and A. Gunji. Effects of 10 and 20 days bed rest on leg muscle mass and strength in young subjects. Acta Physiol. Scand. 150:Suppl. 616:5-18, 1994.

Taylor, H.L., L. Erickson, A. Henschel, and A. Keys. The effect of bed rest on the blood volume of normal young men. Am. J. Physiol. 144:227-232, 1945.

Taylor, H.L, A. Henschel, J. Brozek, and A. Keys. Effects of bed rest on cardiovascular function and work performance. J. Appl. Physiol. 2:223-239, 1949.

Tishchenko, M.I., B.A. Korolev, V.A. Degtyarev, and B.F. Asyamolov. Phase changes in the cardiac cycle during prolonged hypodynamia according to polycardiographic and kinetocardiographic data. Prob. Kosm. Biol. 13:59-64, 1969.
Tizul, A.Ya. The function of thermoregulation in protracted limitation of motor activity (hypokinesia). Z. Nevropatol. Psikhiat. 73:1791-1794, 1973.

Turbasov, V.D. Effect of prolonged antiorthostatic position on cardiac bioelectrical activity according to EKG tracings from corrected orthogonal leads. Kosm. Biol. Aviakosm. Med. 14:54-59, 1980.

Vendt, V.P., L.G. Kindrat'yeva, N.N. Govseyeva, L.I. Apukhovskaya, S.P. Ivashkevich, V.G. Koval, and R.A. Tigranyan. Sterols bound with blood plasma proteins and erythrocyte membranes during hypokinesia. Kosm. Biol. Aviakosm. Med. 13:43-47, 1979.

Vernikos, J., M.F. Dallman, L.C. Keil, D. O'Hara, and V.A. Convertino. Gender differences in endocrine responses to posture and 7 days of -6° head-down bed rest. Am. J. Physiol. Endocrinol. Metab. 265:E153-E161, 1993.

Vernikos-Danellis, J., C.S. Leach, C.M. Winget, A.L. Goodwin, and P.C. Rambaut. Changes in glucose, insulin, and growth hormone levels associated with bedrest. Aviat. Space Environ. Med. 47:583-587, 1976.

Vernikos-Danellis, J., C.M. Winget, C.S. Leach, and P.C. Rambaut. Circadian, endocrine, and metabolic effects of prolonged bedrest: Two 56-day bedrest studies. Moffett Field, CA: NASA Tech. Memo. X-3051, 1974. 42p.

Vetter, W.R., R.W. Sullivan, and K.H. Hyatt. Deterioration of left ventricular function: A consequence of simulated weightlessness. Aerospace Med. Assoc. Preprints: 56-57, 1971.

Vickers, Z.M., B.L. Rice, M.S. Rose, and A.W. Lane. Simulated microgravity [bed rest] has little influence on taste, odor, or trigeminal sensitivity. J. Sensory Studies 16:23-32, 2001.

Vlasova, T.F., Ye.B. Miroshnikova, and A.S. Ushakov. Investigation of some aspects of human amino acid metabolism during 120-day antiorthostatic hypokinesia. Kosm. Biol. Aviakosm. Med. 19:35-38, 1985.

Vogt, F.B, P.B. Mack, and P.C. Johnson. Tilt table response and blood volume changes associated with thirty days of recumbency. Aerospace Med. 37:771-777, 1966.

Vogt, F.B, P.B. Mack, P.C. Johnson, and L. Wade Jr. Tilt table response and blood volume changes associated with fourteen days of recumbency. Aerospace Med. 38:43-48, 1967.

Vorob'yev, V.Ye., V.R. Abdrakhmanov, A.P. Golikov, L.L. Stazhadze, I.B. Goncharov, I.V. Kovachevich, S.G. Voronina, and A.V. Vabishchevich. Effect of 120-day antiorthostatic bedrest on gas exchange and pulmonary circulation in man. Kosm. Biol. Aviakosm. Med. 18:23-26, 1984.

Vorob'yev, V.Ye., V.R. Abdrakhmanov, I.V. Kovachevich, A.P. Golikov, L.L. Stazhadze, V.V. Bogomolov, S.G. Voronina, and L.G. Repenkova. Effect of hypokinesia in antiorthostatic position on pulmonary circulation and gas exhange. Kosm. Biol. Aviakosm. Med. 17:16-18, 1983.

Voskresenskiy, A.D., B.B. Yegorov, I.D. Pestov, S.M. Belyashin, V.M. Tolstov, and I.S. Lezhin. Organization of the experiments and overall condition of the subjects. Kosm. Biol. Aviakosm. Med. 6:28-32, 1972.

Whedon, G.D., J.E. Deitrick, E. Shorr, V. Toscani, V.B. Davis, and E. Stevens. Modification of the effects of immobilization upon metabolic and physiologic functions of normal men by the use of an oscillating bed. Am. J. Med. 6:684-711, 1949.

White, P.D., J.W. Nyberg, L.M. Finney, and W.J. White. Influence of periodic centrifugation on cardiovascular functions of man during bed rest. Santa Monica, CA: Douglas Aircraft Co., Inc. Rept. DAC-59286, 1966. 47p.

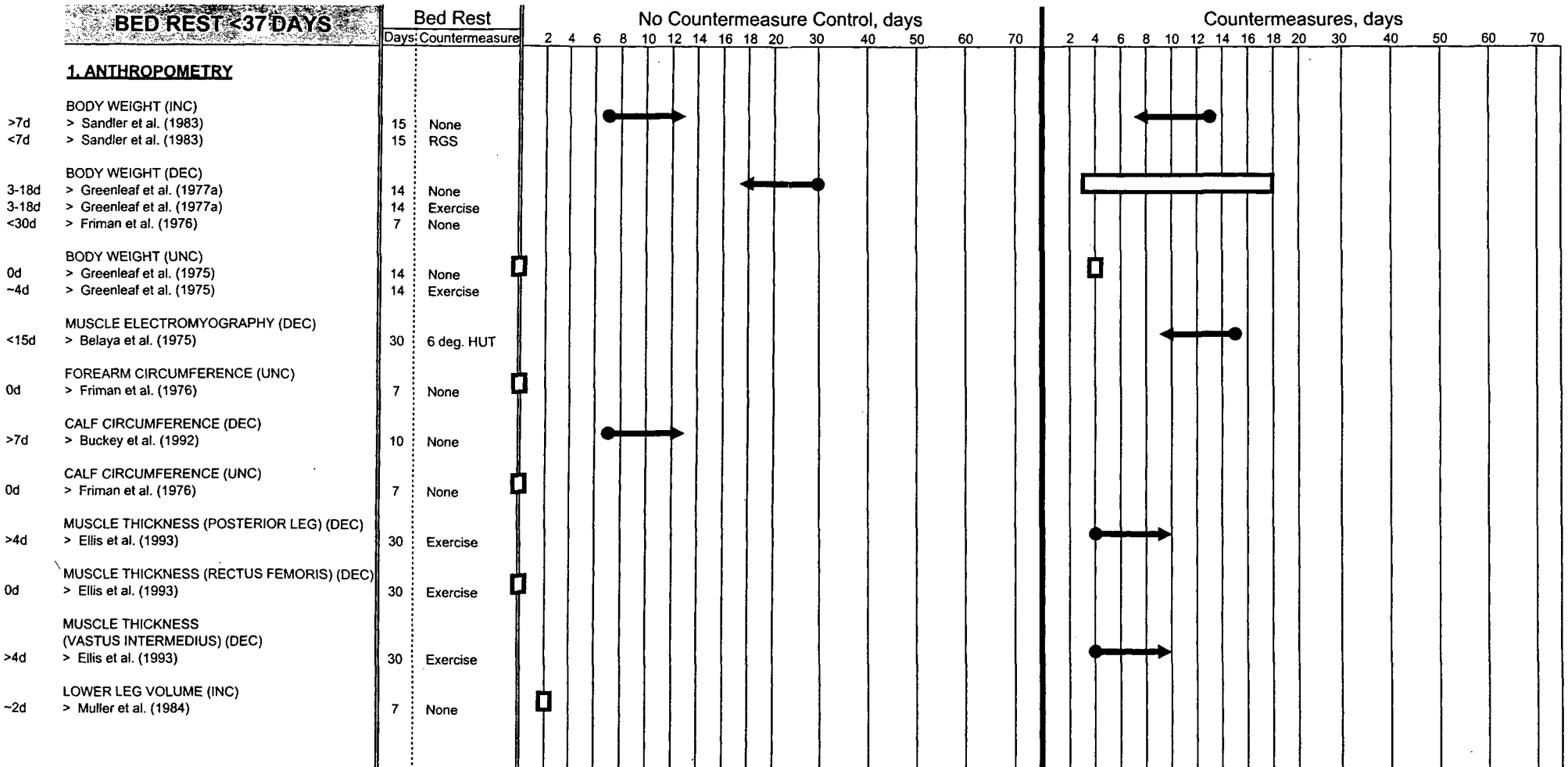
Winget, C.M., J. Vernikos-Danellis, C.W. Deroshia, S.E. Cronin, C. Leach, and P.C. Rambaut. Rhythms during hypokinesis. In: Biorhythms and Human Reproduction Series: Seminars in Reproduction, edited by M. Ferin, F. Halberg, R. Richart, and R. Vande Wiele. New York: Wiley & Sons, Chapt. 38, 1974, pp. 575-581.

Yarullin, Kh.Kh., L.G. Simonov, and S.A. Vtoryy. Changes in regional and central hemodynamics during seven-day water immersion. Kosm. Biol. Aviakosm. Med. 21:45-50, 1987.

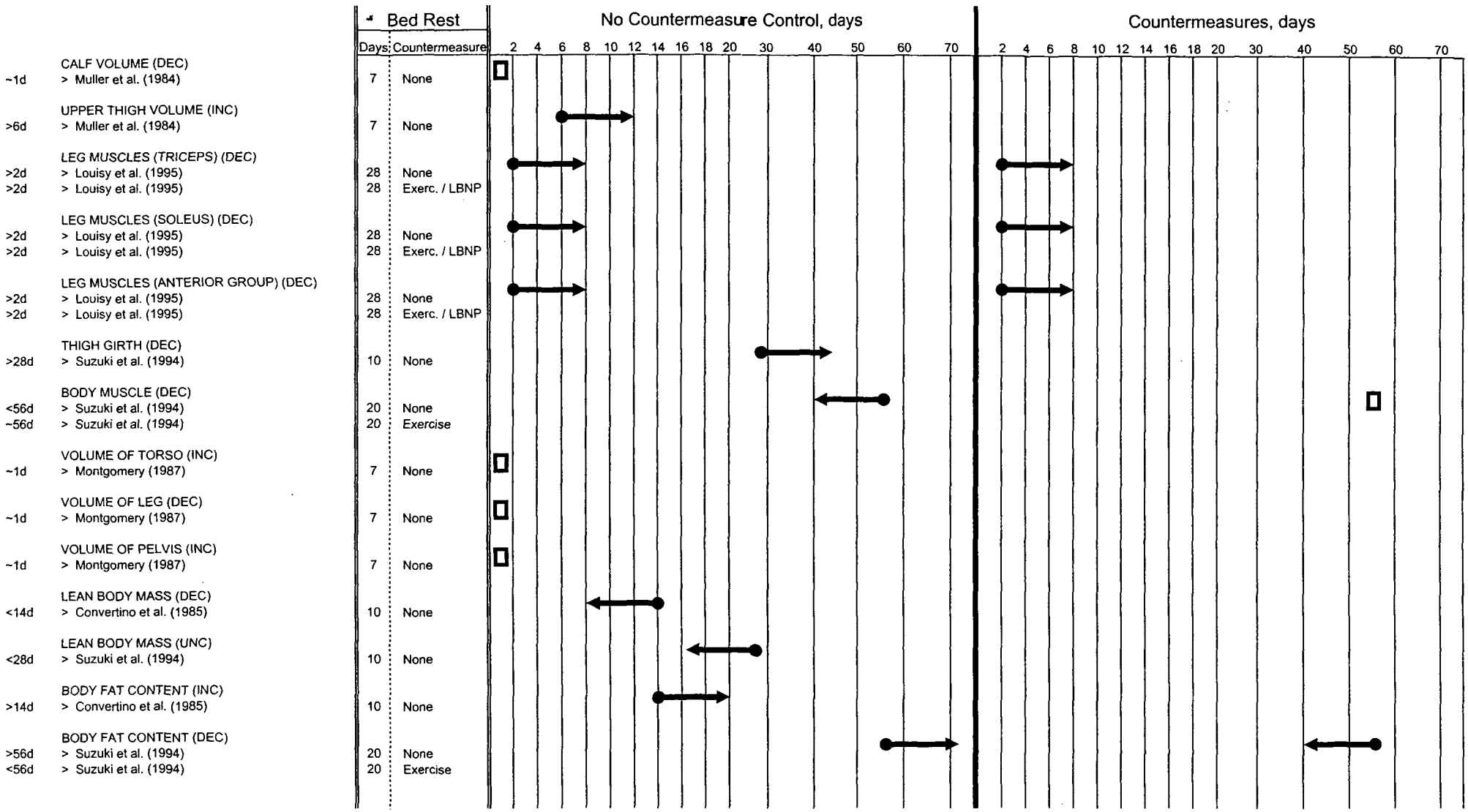
Zatsiorskiy, V.M., M.G. Sirota, B.I. Prilutskiy, L.M. Raytsin, V.N. Seluyanov, and L.G. Chugunova. Human body biomechanics and movements after 120-day antiorthostatic hypokinesia. Kosm. Biol. Aviakosm. Med. 19:23-27, 1985.

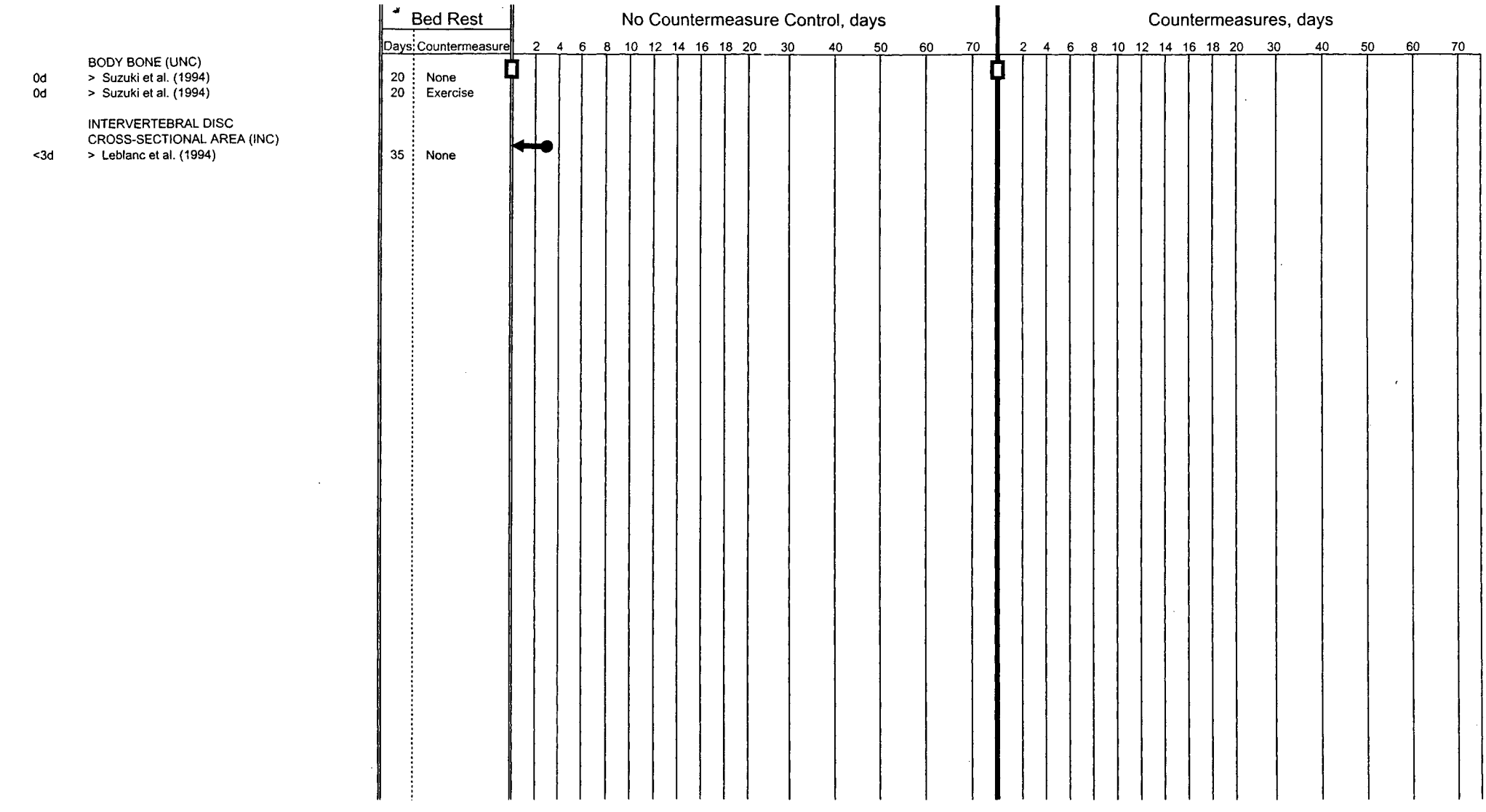
Zhiznevskaya, O.V., and I.L. Medkova. Investigation of spectrum of human bile acids during 120-day antiorthostatic hypokinesia. Kosm. Biol. Aviakosm. Med. 19:33-35, 1985.

Figure 1. Recovery data for bed-rest periods less than 37 days.



INC = increase; DEC = decrease; UNC = unchange; LBNP = lower body negative pressure; RGS = reverse gradient suit;
# = countermeasure done during Recovery period; HUT = head up tilt


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
CALF VOLUME (DEC)
~1d > Muller et al. (1984) 7 None
UPPER THIGH VOLUME (INC)
>6d > Muller et al. (1984) 7 None
LEG MUSCLES (TRICEPS) (DEC)
>2d > Louisy et al. (1995) 28 None
>2d > Louisy et al. (1995) 28 Exerc. / LBNP
LEG MUSCLES (SOLEUS) (DEC)
>2d > Louisy et al. (1995) 28 None
>2d > Louisy et al. (1995) 28 Exerc. / LBNP
LEG MUSCLES (ANTERIOR GROUP) (DEC)
>2d > Louisy et al. (1995) 28 None
>2d > Louisy et al. (1995) 28 Exerc. / LBNP
THIGH GIRTH (DEC)
>28d > Suzuki et al. (1994) 10 None
BODY MUSCLE (DEC)
<56d > Suzuki et al. (1994) 20 None
~56d > Suzuki et al. (1994) 20 Exercise
VOLUME OF TORSO (INC)
~1d > Montgomery (1987) 7 None
VOLUME OF LEG (DEC)
~1d > Montgomery (1987) 7 None
VOLUME OF PELVIS (INC)
~1d > Montgomery (1987) 7 None
LEAN BODY MASS (DEC)
<14d > Convertino et al. (1985) 10 None
LEAN BODY MASS (UNC)
<28d > Suzuki et al. (1994) 10 None
BODY FAT CONTENT (INC)
>14d > Convertino et al. (1985) 10 None
BODY FAT CONTENT (DEC)
>56d > Suzuki et al. (1994) 20 None
<56d > Suzuki et al. (1994) 20 Exercise


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
BODY BONE (UNC)
0d > Suzuki et al. (1994) 20 None
0d > Suzuki et al. (1994) 20 Exercise
INTERVERTEBRAL DISC CROSS-SECTIONAL AREA (INC)
<3d > Leblanc et al. (1994) 35 None

2. PHYSIOLOGICAL SYSTEMS

2A. Cardiovascular Variables

BASAL HEART RATE (INC)
~3d > Greenleaf et al. (1975)
~1d > Greenleaf et al. (1975)

HEART RATE, with tilting (INC)
~42d > Whedon et al. (1949)
>3d > Vogt et al. (1967)

HEART RATE (INC)
>3d > Arbeille et al. (1992)
0d > Maillet et al. (1995)
8-13d > Georgievskii et al. (1966)
<63d # > Kashihara et al. (1994)
<63d # > Kashihara et al. (1994)

HEART RATE (UNC)
>1d > Katkov et al. (1983)
0d > Polese et al. (1980)
>2d > Katkovskiy et al. (1971)

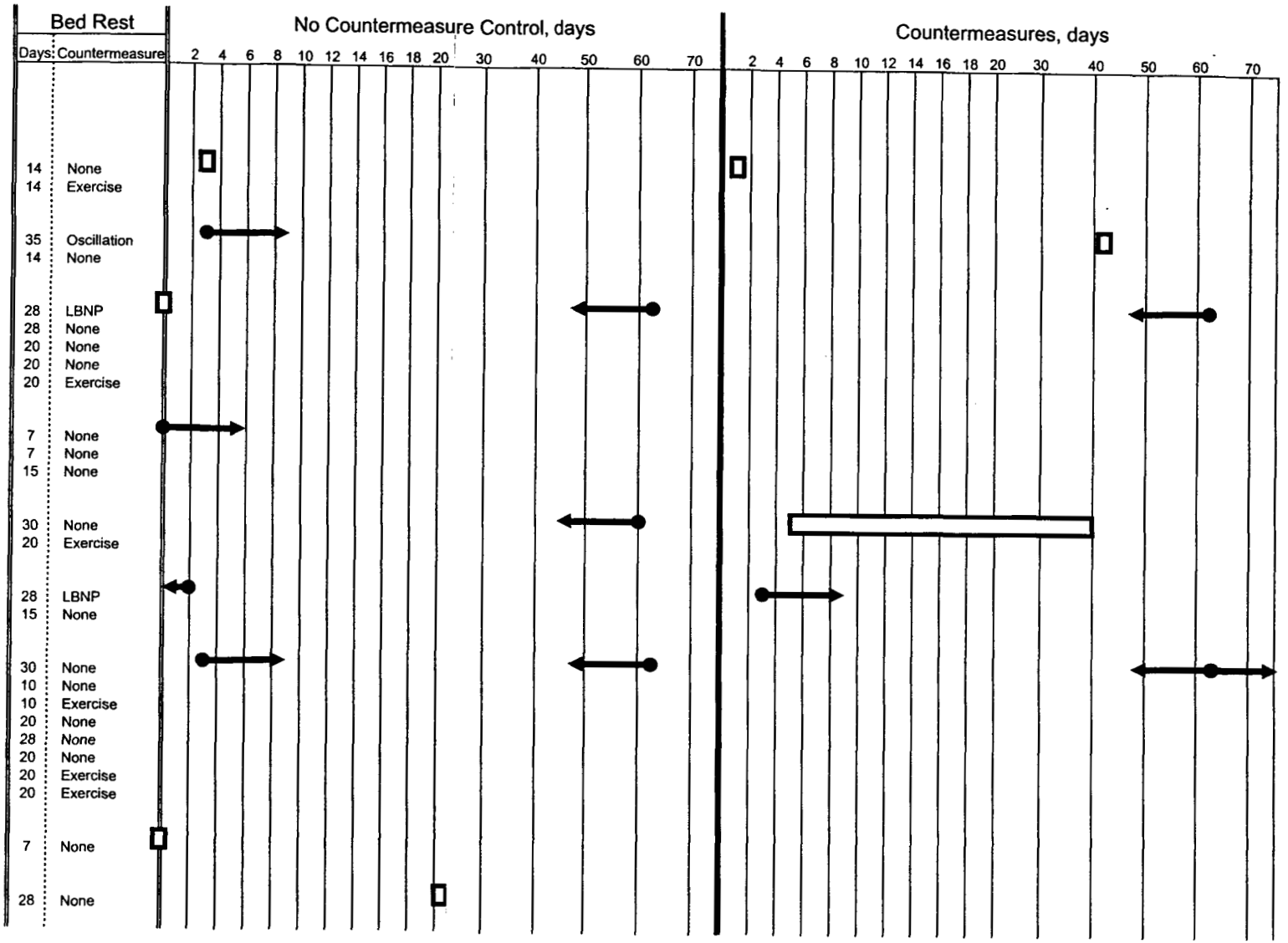
HEART VOLUME (DEC)
<60d > Krasnych (1973)
5-40d # > Saltin et al. (1968)

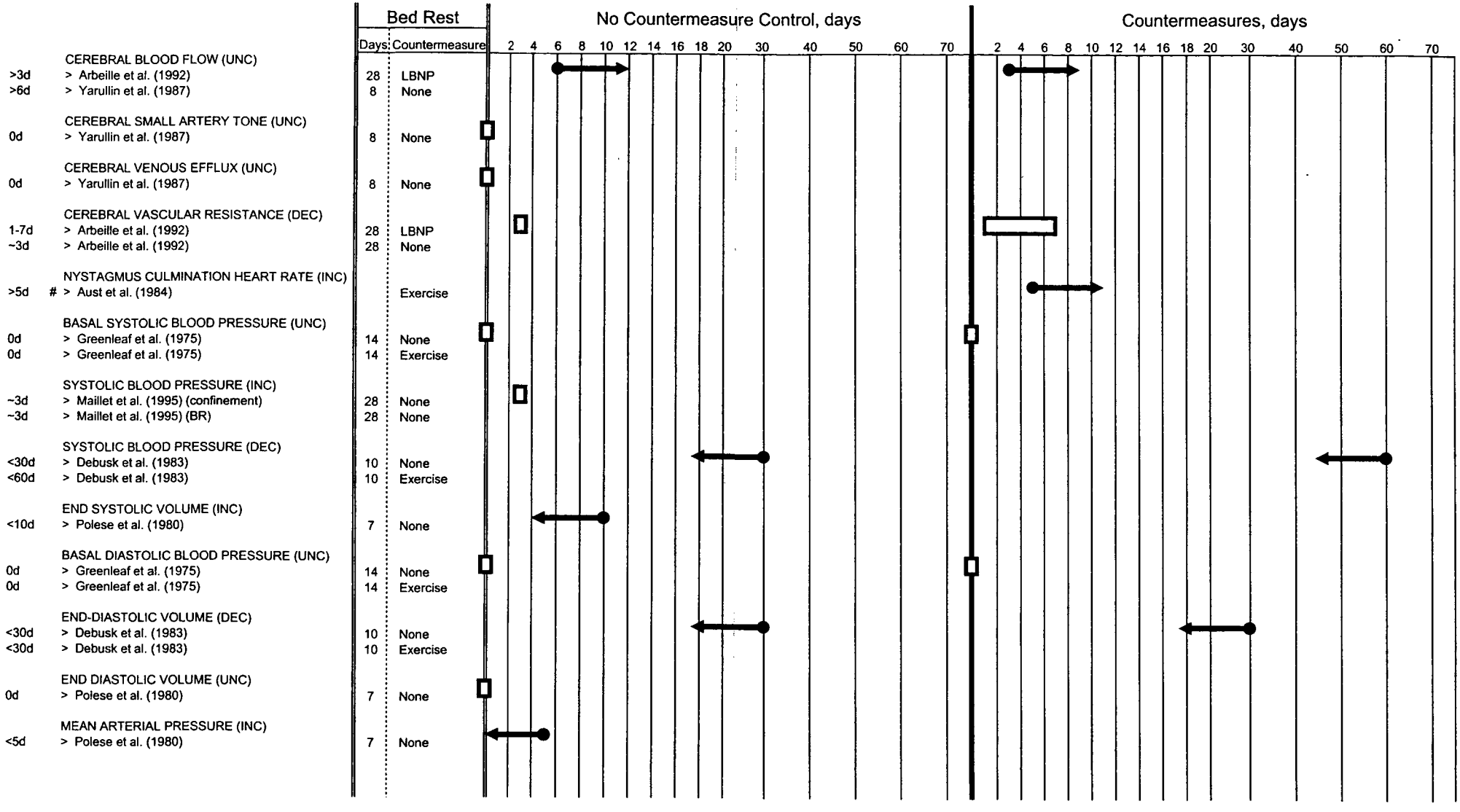
HEART STROKE VOLUME (INC)
>3d > Arbeille et al. (1992)
<2d > Katkovskiy et al. (1971)

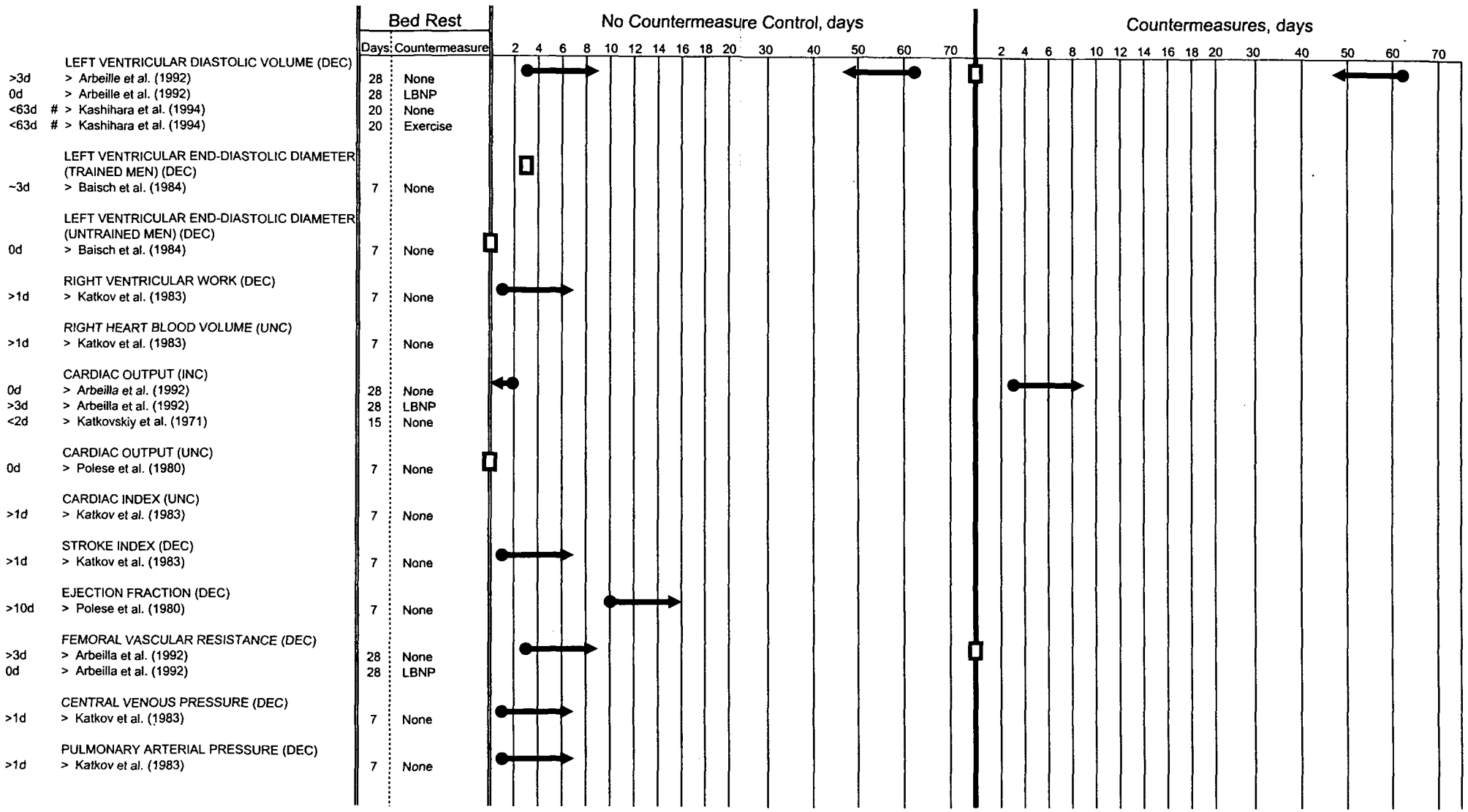
HEART STROKE VOLUME (DEC)
<60d > Krasnych (1973)
<60d > Debusk et al. (1983)
<30d > Debusk et al. (1983)
8-13d > Georgievskii et al. (1966)
>3d > Arbeille et al. (1992)
<63d # > Kashihara et al. (1994)
<63d # > Kashihara et al. (1994)
>63d # > Kashihara et al. (1994)

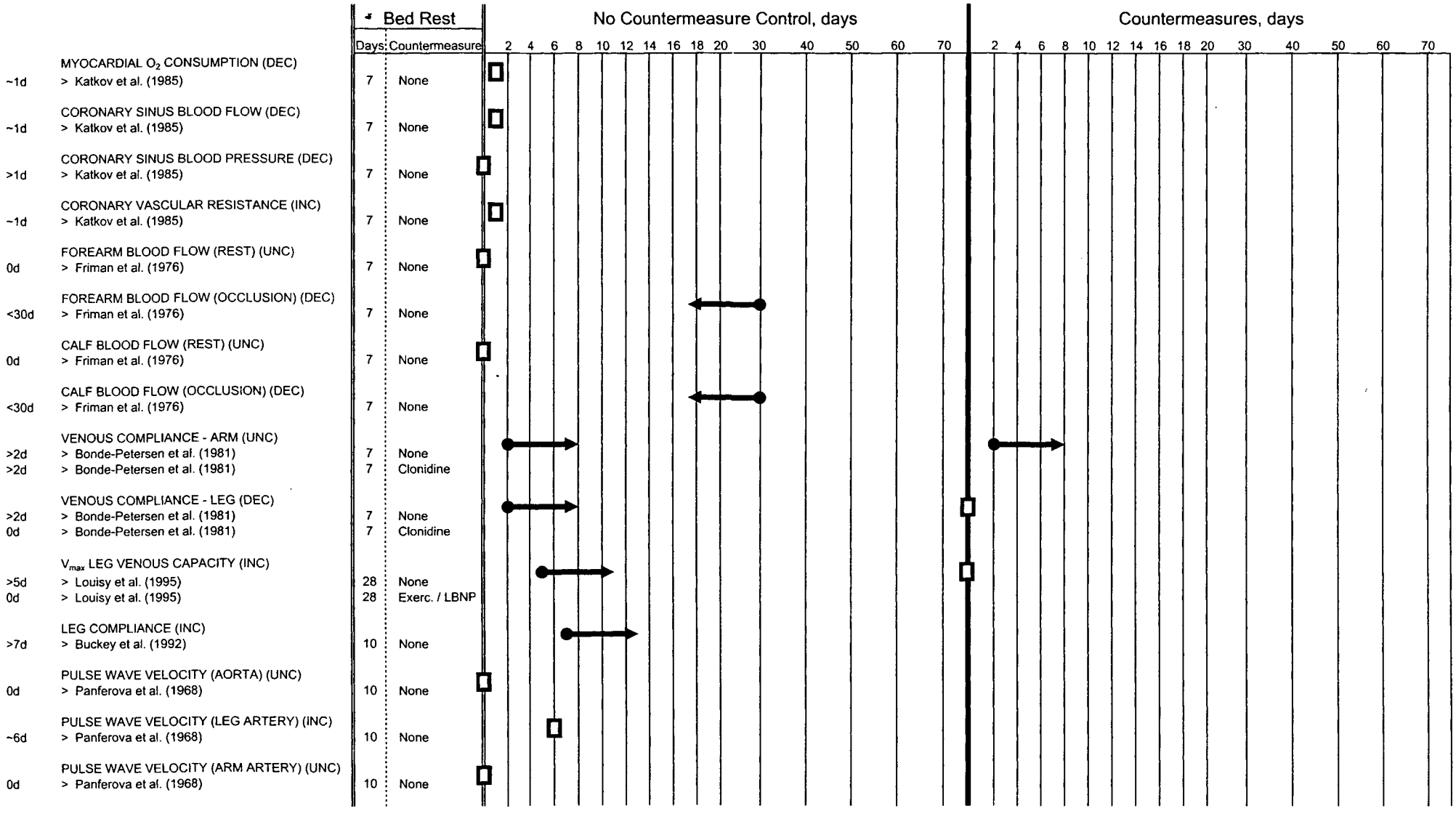
HEART STROKE VOLUME (UNC)
0d > Polese et al. (1980)

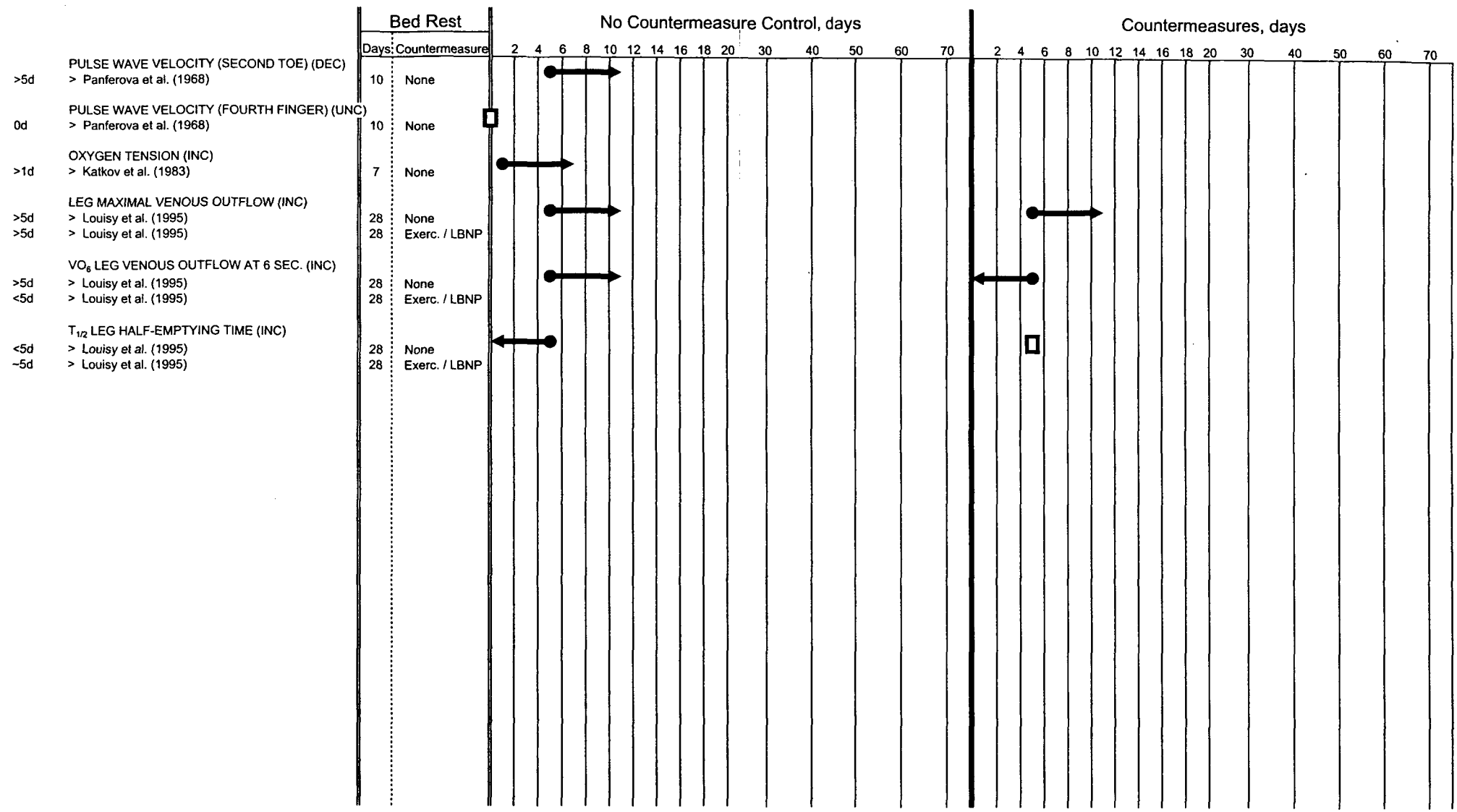
HEART VENTRICULAR FUNCTION (DEC)
~21d > Vetter et al. (1971)



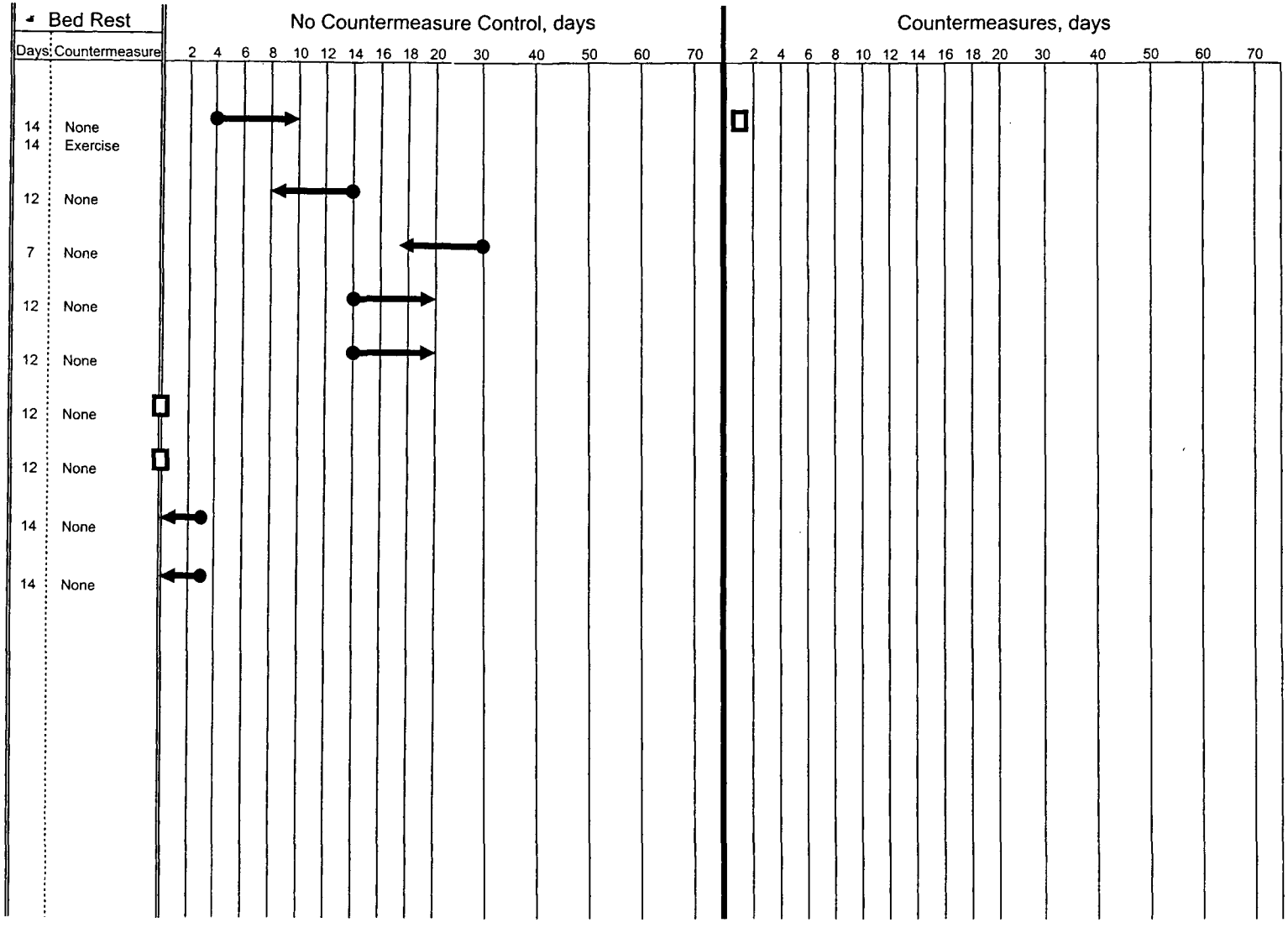

Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
CEREBRAL BLOOD FLOW (UNC)
>3d > Arbeille et al. (1992) 28 LBNP
>6d > Yarullin et al. (1987) 8 None
CEREBRAL SMALL ARTERY TONE (UNC)
0d > Yarullin et al. (1987) 8 None
CEREBRAL VENOUS EFFLUX (UNC)
0d > Yarullin et al. (1987) 8 None
CEREBRAL VASCULAR RESISTANCE (DEC)
1-7d > Arbeille et al. (1992) 28 LBNP
~3d > Arbeille et al. (1992) 28 None
NYSTAGMUS CULMINATION HEART RATE (INC)
>5d # > Aust et al. (1984) Exercise
BASAL SYSTOLIC BLOOD PRESSURE (UNC)
0d > Greenleaf et al. (1975) 14 None
0d > Greenleaf et al. (1975) 14 Exercise
SYSTOLIC BLOOD PRESSURE (INC)
~3d > Maillet et al. (1995) (confinement) 28 None
~3d > Maillet et al. (1995) (BR) 28 None
SYSTOLIC BLOOD PRESSURE (DEC)
<30d > Debusk et al. (1983) 10 None
<60d > Debusk et al. (1983) 10 Exercise
END SYSTOLIC VOLUME (INC)
<10d > Polese et al. (1980) 7 None
BASAL DIASTOLIC BLOOD PRESSURE (UNC)
0d > Greenleaf et al. (1975) 14 None
0d > Greenleaf et al. (1975) 14 Exercise
END-DIASTOLIC VOLUME (DEC)
<30d > Debusk et al. (1983) 10 None
<30d > Debusk et al. (1983) 10 Exercise
END DIASTOLIC VOLUME (UNC)
0d > Polese et al. (1980) 7 None
MEAN ARTERIAL PRESSURE (INC)
<5d > Polese et al. (1980) 7 None


Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
LEFT VENTRICULAR DIASTOLIC VOLUME (DEC)
>3d > Arbeille et al. (1992) 28 None
0d > Arbeille et al. (1992) 28 LBNP
<63d # > Kashihara et al. (1994) 20 None
<63d # > Kashihara et al. (1994) 20 Exercise
LEFT VENTRICULAR END-DIASTOLIC DIAMETER (TRAINED MEN) (DEC)
~3d > Baisch et al. (1984) 7 None
LEFT VENTRICULAR END-DIASTOLIC DIAMETER (UNTRAINED MEN) (DEC)
0d > Baisch et al. (1984) 7 None
RIGHT VENTRICULAR WORK (DEC)
>1d > Katkov et al. (1983) 7 None
RIGHT HEART BLOOD VOLUME (UNC)
>1d > Katkov et al. (1983) 7 None
CARDIAC OUTPUT (INC)
0d > Arbeilla et al. (1992) 28 None
>3d > Arbeilla et al. (1992) 28 LBNP
<2d > Katkovskiy et al. (1971) 15 None
CARDIAC OUTPUT (UNC)
0d > Polese et al. (1980) 7 None
CARDIAC INDEX (UNC)
>1d > Katkov et al. (1983) 7 None
STROKE INDEX (DEC)
>1d > Katkov et al. (1983) 7 None
EJECTION FRACTION (DEC)
>10d > Polese et al. (1980) 7 None
FEMORAL VASCULAR RESISTANCE (DEC)
>3d > Arbeilla et al. (1992) 28 None
0d > Arbeilla et al. (1992) 28 LBNP
CENTRAL VENOUS PRESSURE (DEC)
>1d > Katkov et al. (1983) 7 None
PULMONARY ARTERIAL PRESSURE (DEC)
>1d > Katkov et al. (1983) 7 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
MYOCARDIAL O_2 CONSUMPTION (DEC)
~1d > Katkov et al. (1985) 7 None
CORONARY SINUS BLOOD FLOW (DEC)
~1d > Katkov et al. (1985) 7 None
CORONARY SINUS BLOOD PRESSURE (DEC)
>1d > Katkov et al. (1985) 7 None
CORONARY VASCULAR RESISTANCE (INC)
~1d > Katkov et al. (1985) 7 None
FOREARM BLOOD FLOW (REST) (UNC)
0d > Friman et al. (1976) 7 None
FOREARM BLOOD FLOW (OCCLUSION) (DEC)
<30d > Friman et al. (1976) 7 None
CALF BLOOD FLOW (REST) (UNC)
0d > Friman et al. (1976) 7 None
CALF BLOOD FLOW (OCCLUSION) (DEC)
<30d > Friman et al. (1976) 7 None
VENOUS COMPLIANCE - ARM (UNC)
>2d > Bonde-Petersen et al. (1981) 7 None
>2d > Bonde-Petersen et al. (1981) 7 Clonidine
VENOUS COMPLIANCE - LEG (DEC)
>2d > Bonde-Petersen et al. (1981) 7 None
0d > Bonde-Petersen et al. (1981) 7 Clonidine
V_{max} LEG VENOUS CAPACITY (INC)
>5d > Louisy et al. (1995) 28 None
0d > Louisy et al. (1995) 28 Exerc. / LBNP
LEG COMPLIANCE (INC)
>7d > Buckey et al. (1992) 10 None
PULSE WAVE VELOCITY (AORTA) (UNC)
0d > Panferova et al. (1968) 10 None
PULSE WAVE VELOCITY (LEG ARTERY) (INC)
~6d > Panferova et al. (1968) 10 None
PULSE WAVE VELOCITY (ARM ARTERY) (UNC)
0d > Panferova et al. (1968) 10 None

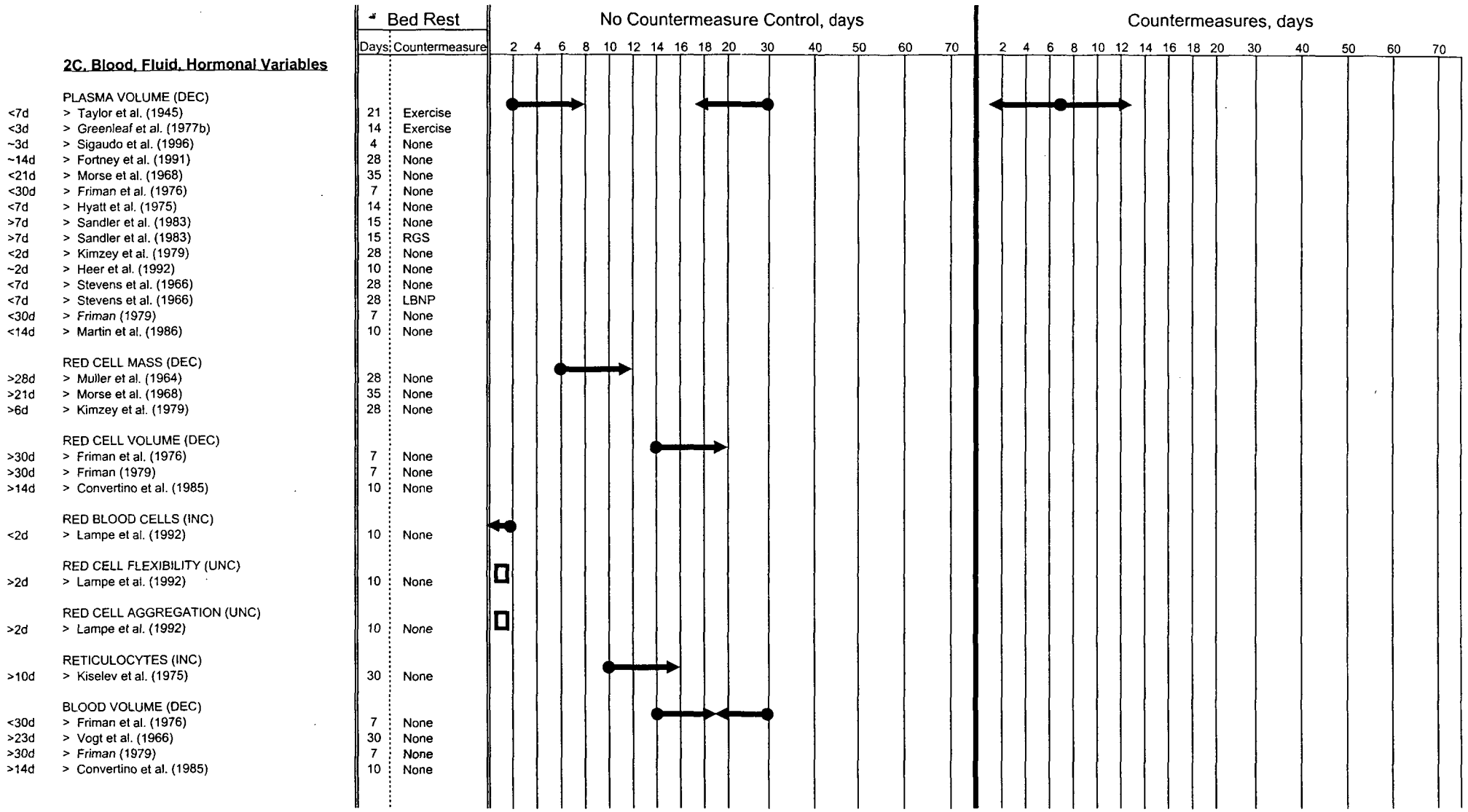

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
PULSE WAVE VELOCITY (SECOND TOE) (DEC)
>5d > Panferova et al. (1968) 10 None
PULSE WAVE VELOCITY (FOURTH FINGER) (UNC)
0d > Panferova et al. (1968) 10 None
OXYGEN TENSION (INC)
>1d > Katkov et al. (1983) 7 None
LEG MAXIMAL VENOUS OUTFLOW (INC)
>5d > Louisy et al. (1995) 28 None
>5d > Louisy et al. (1995) 28 Exerc. / LBNP
VO6 LEG VENOUS OUTFLOW AT 6 SEC. (INC)
>5d > Louisy et al. (1995) 28 None
<5d > Louisy et al. (1995) 28 Exerc. / LBNP
T1/2 LEG HALF-EMPTYING TIME (INC)
<5d > Louisy et al. (1995) 28 None
~5d > Louisy et al. (1995) 28 Exerc. / LBNP

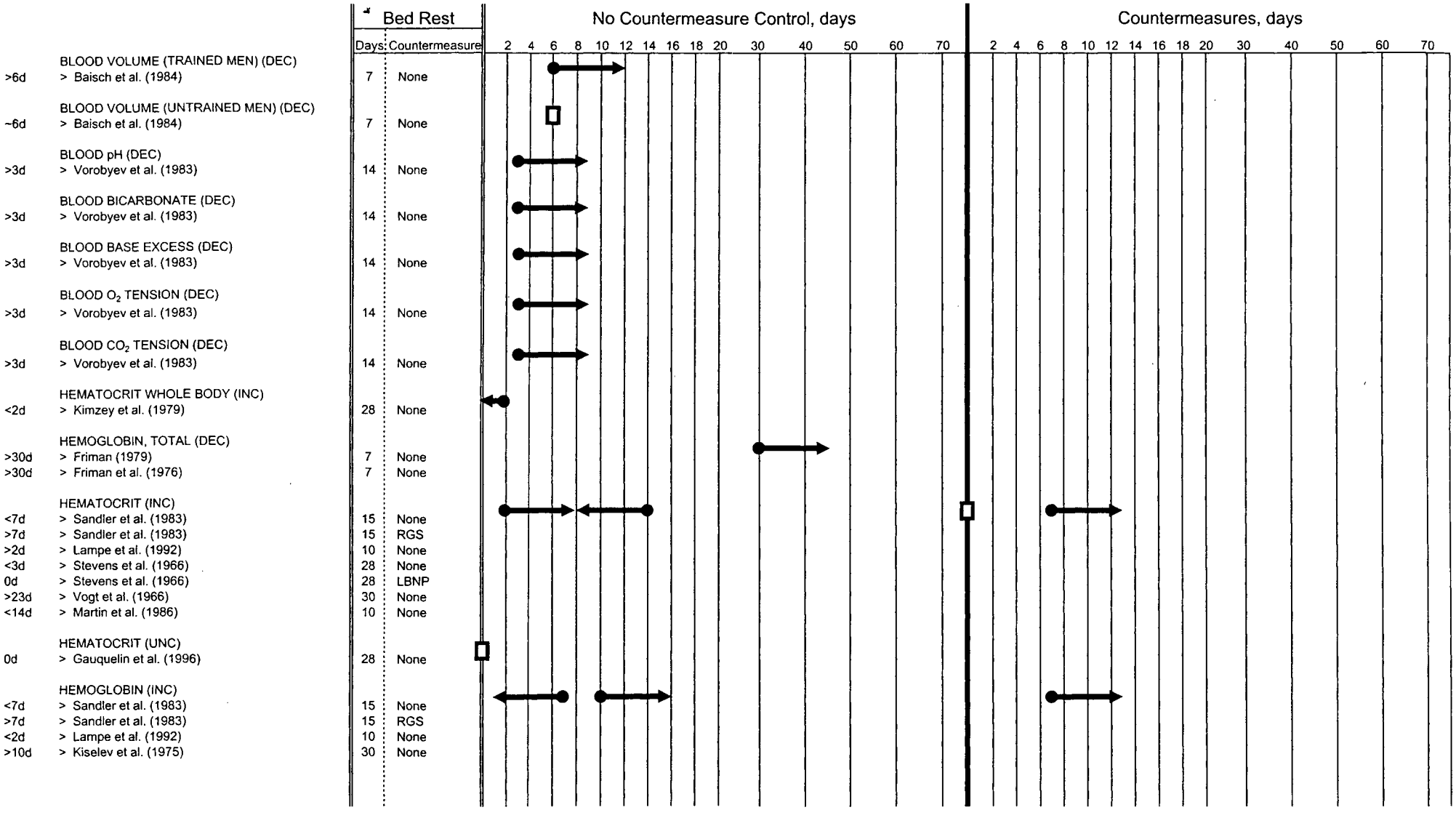
2B. Respiratory Variables

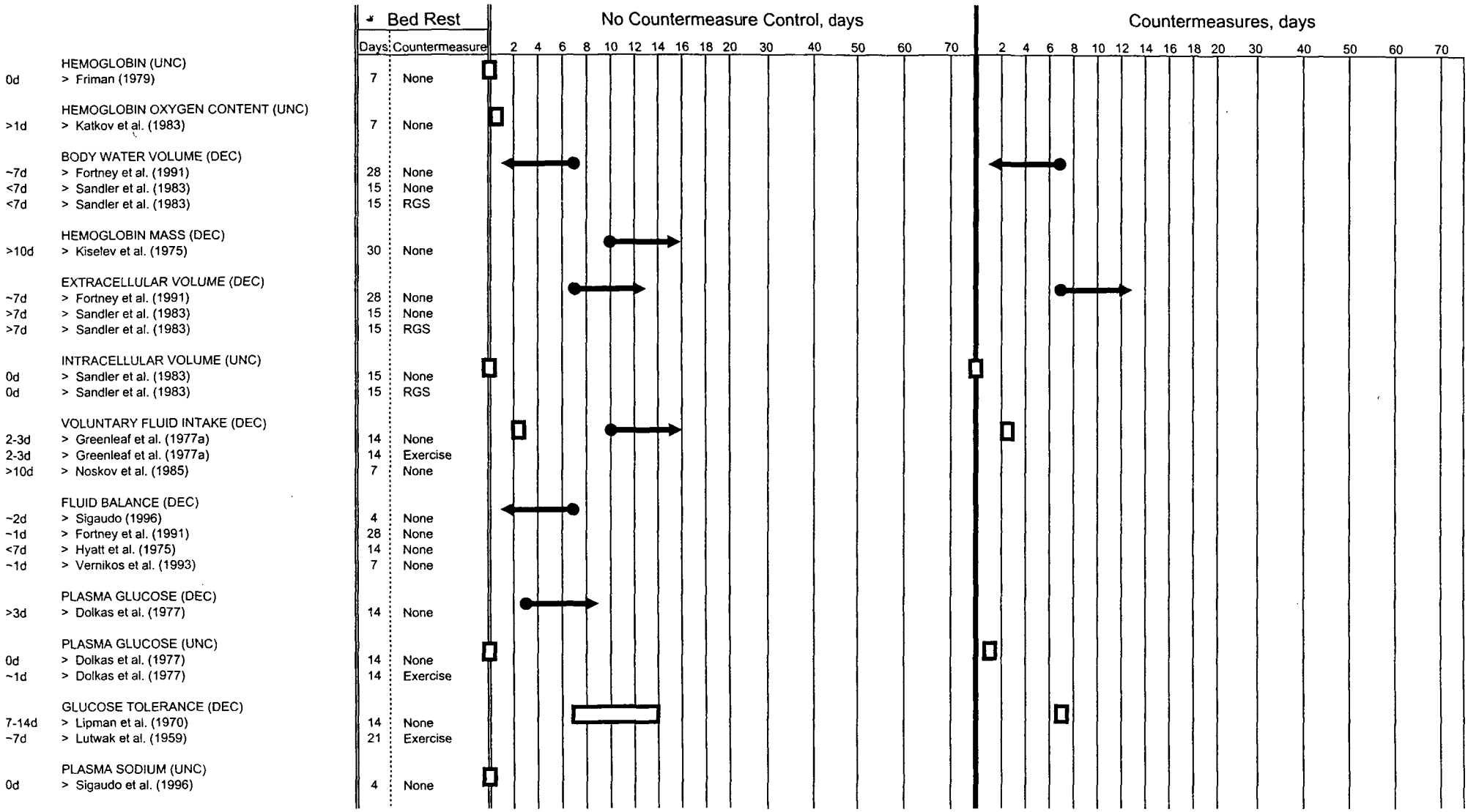


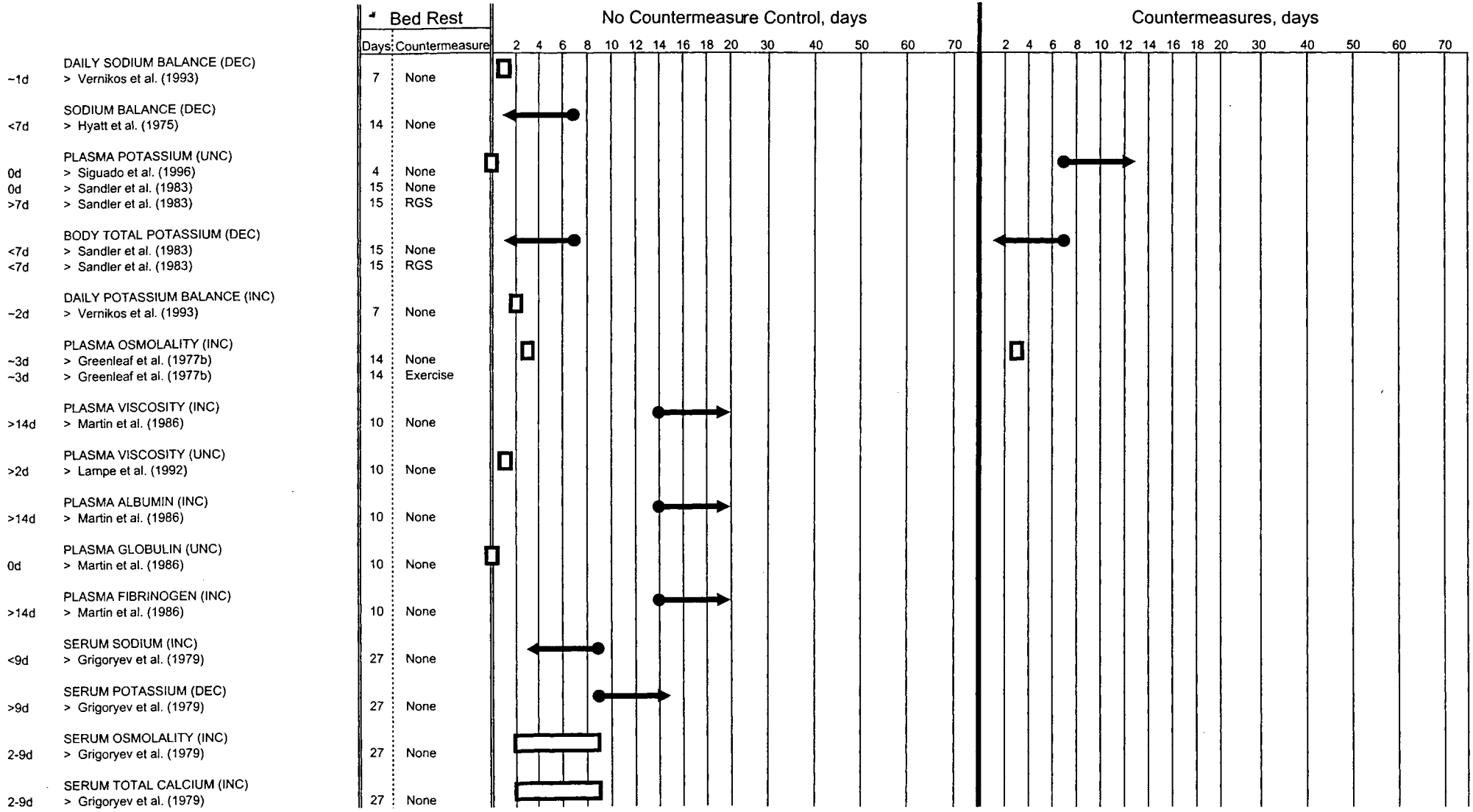
		Days	Countermeasure
	BASAL RESPIRATORY RATE (DEC)		
>4d	> Greenleaf et al. (1975)	14	None
~1d	> Greenleaf et al. (1975)	14	Exercise
	FORCED VITAL CAPACITY (INC)		
<14d	> Beckett et al. (1986)	12	None
	MAXIMAL VENTILATION (DEC)		
<30d	> Friman (1979)	7	None
	FORCED EXPIRATORY VOLUME (INC)		
>14d	> Beckett et al. (1986)	12	None
	TOTAL LUNG CAPACITY (INC)		
>14d	> Beckett et al. (1986)	12	None
	FUNCTIONAL RESIDUAL CAPACITY (UNC)		
0d	> Beckett et al. (1986)	12	None
	RESIDUAL VOLUME (UNC)		
0d	> Beckett et al. (1986)	12	None
	O_2 AVEOLAR-ARTERIAL GRADIENT (INC)		
<3d	> Vorobyev et al. (1983)	14	None
	CO_2 ALVEOLAR-ARTERIAL GRADIENT (INC)		
<3d	> Vorobyev et al. (1983)	14	None

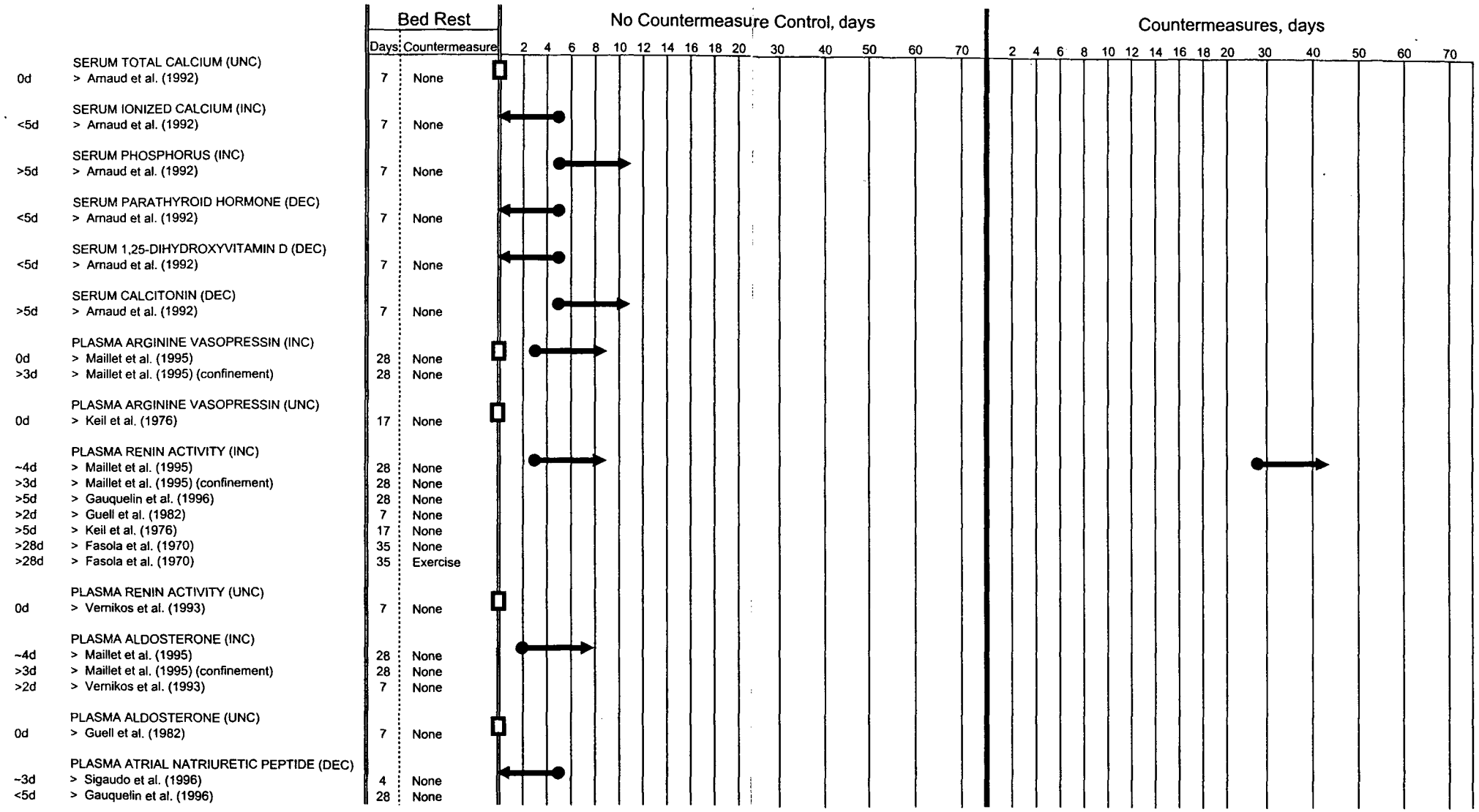
2C. Blood, Fluid, Hormonal Variables

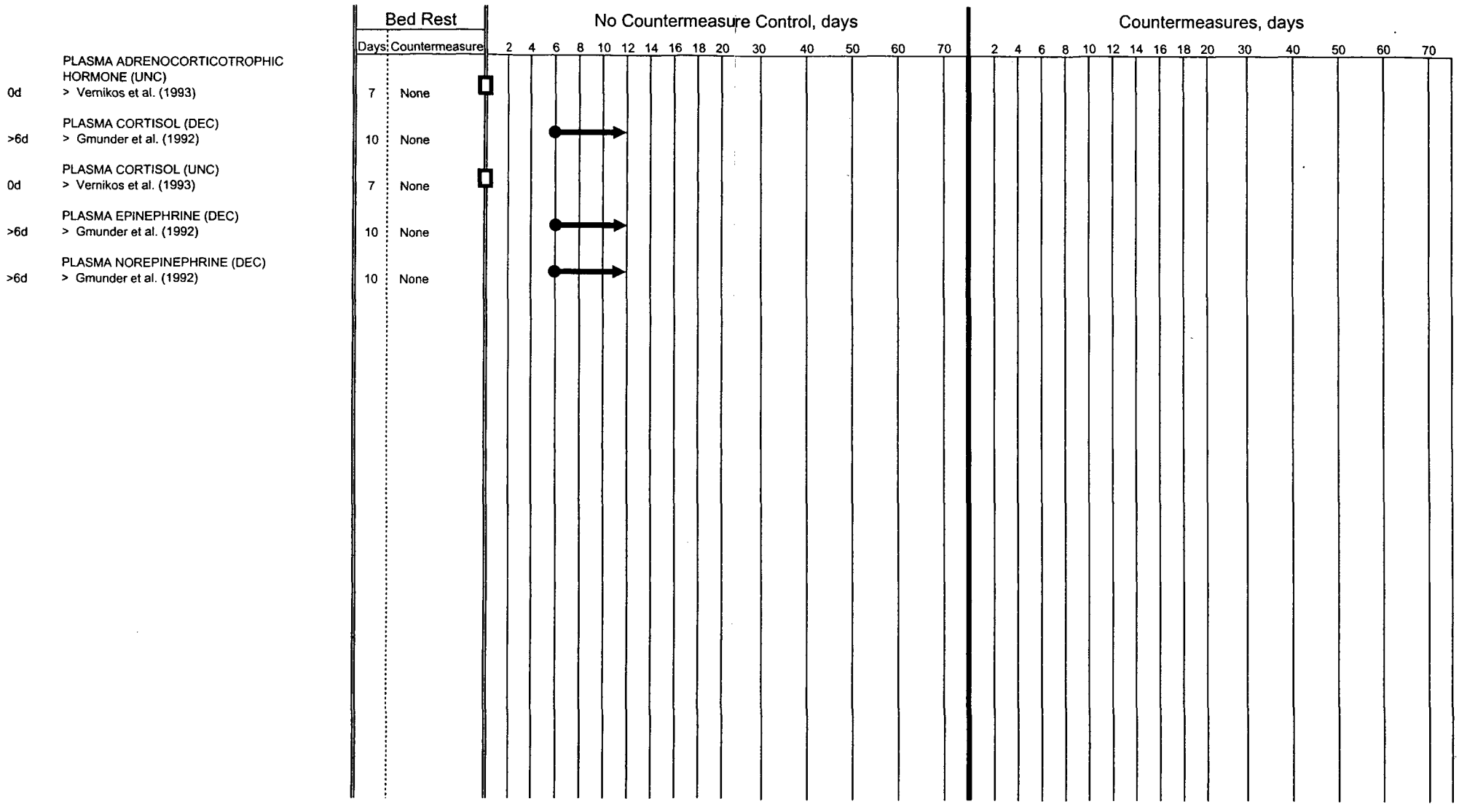


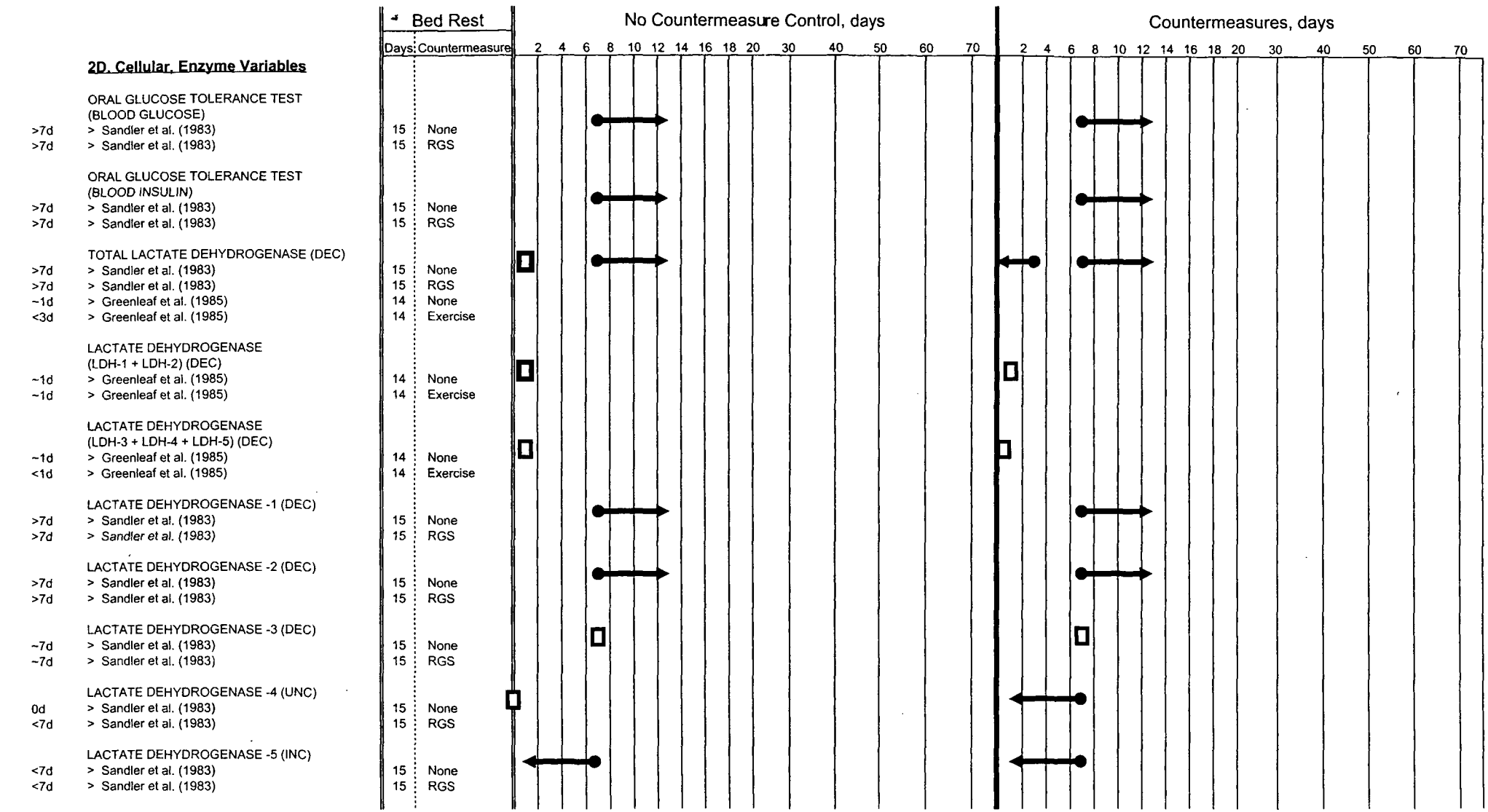

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
BLOOD VOLUME (TRAINED MEN) (DEC)
>6d > Baisch et al. (1984) 7 None
BLOOD VOLUME (UNTRAINED MEN) (DEC)
~6d > Baisch et al. (1984) 7 None
BLOOD pH (DEC)
>3d > Vorobyev et al. (1983) 14 None
BLOOD BICARBONATE (DEC)
>3d > Vorobyev et al. (1983) 14 None
BLOOD BASE EXCESS (DEC)
>3d > Vorobyev et al. (1983) 14 None
BLOOD O_2 TENSION (DEC)
>3d > Vorobyev et al. (1983) 14 None
BLOOD CO_2 TENSION (DEC)
>3d > Vorobyev et al. (1983) 14 None
HEMATOCRIT WHOLE BODY (INC)
<2d > Kimzey et al. (1979) 28 None
HEMOGLOBIN, TOTAL (DEC)
>30d > Friman (1979) 7 None
>30d > Friman et al. (1976) 7 None
HEMATOCRIT (INC)
<7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
>2d > Lampe et al. (1992) 10 None
<3d > Stevens et al. (1966) 28 None
0d > Stevens et al. (1966) 28 LBNP
>23d > Vogt et al. (1966) 30 None
<14d > Martin et al. (1986) 10 None
HEMATOCRIT (UNC)
0d > Gauquelin et al. (1996) 28 None
HEMOGLOBIN (INC)
<7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
<2d > Lampe et al. (1992) 10 None
>10d > Kiselev et al. (1975) 30 None

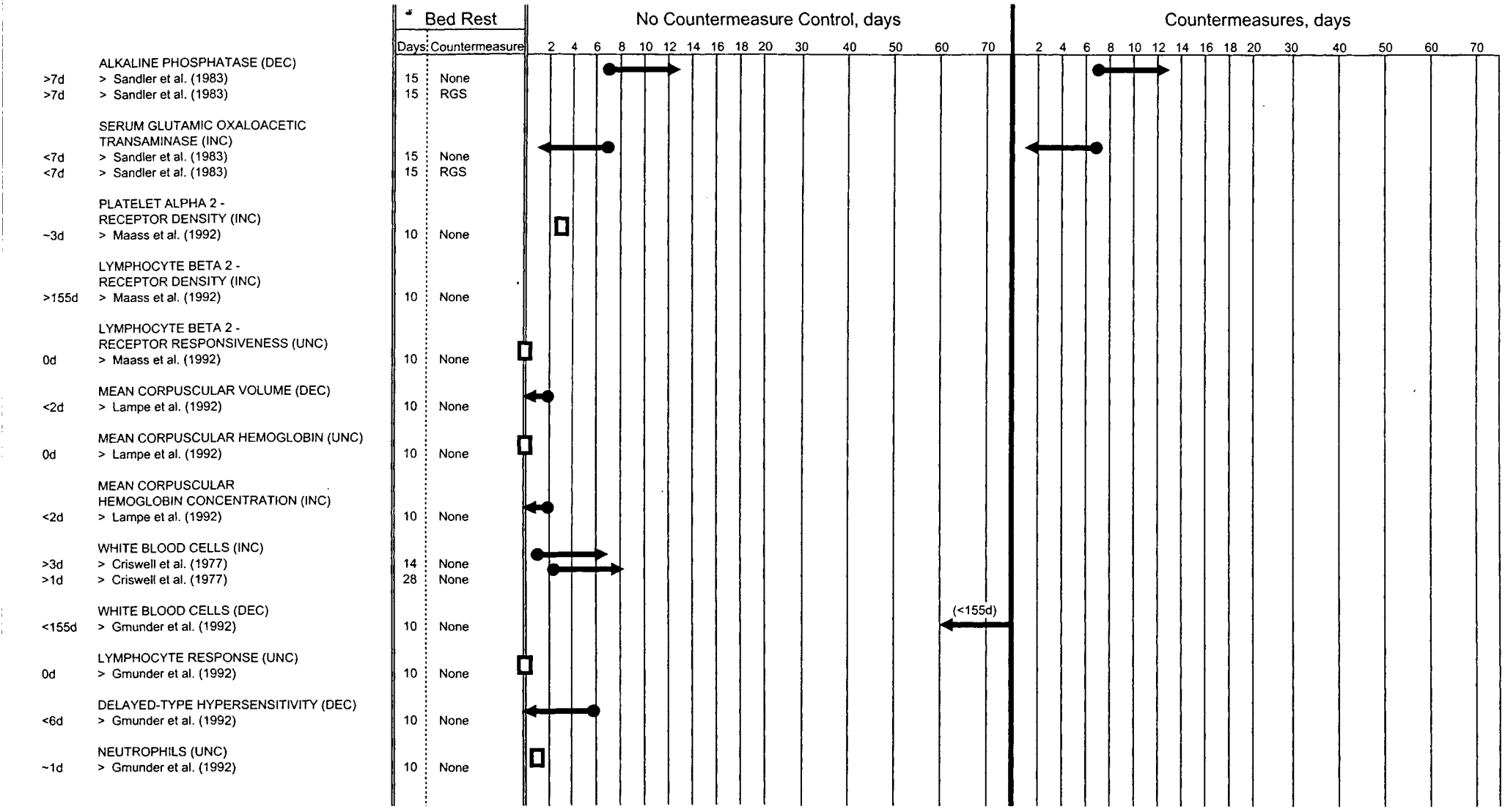

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
HEMOGLOBIN (UNC)
0d > Friman (1979) 7 None
HEMOGLOBIN OXYGEN CONTENT (UNC)
>1d > Katkov et al. (1983) 7 None
BODY WATER VOLUME (DEC)
~7d > Fortney et al. (1991) 28 None
<7d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS
HEMOGLOBIN MASS (DEC)
>10d > Kiselev et al. (1975) 30 None
EXTRACELLULAR VOLUME (DEC)
~7d > Fortney et al. (1991) 28 None
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
INTRACELLULAR VOLUME (UNC)
0d > Sandler et al. (1983) 15 None
0d > Sandler et al. (1983) 15 RGS
VOLUNTARY FLUID INTAKE (DEC)
2-3d > Greenleaf et al. (1977a) 14 None
2-3d > Greenleaf et al. (1977a) 14 Exercise
>10d > Noskov et al. (1985) 7 None
FLUID BALANCE (DEC)
~2d > Sigaudo (1996) 4 None
~1d > Fortney et al. (1991) 28 None
<7d > Hyatt et al. (1975) 14 None
~1d > Vernikos et al. (1993) 7 None
PLASMA GLUCOSE (DEC)
>3d > Dolkas et al. (1977) 14 None
PLASMA GLUCOSE (UNC)
0d > Dolkas et al. (1977) 14 None
~1d > Dolkas et al. (1977) 14 Exercise
GLUCOSE TOLERANCE (DEC)
7-14d > Lipman et al. (1970) 14 None
~7d > Lutwak et al. (1959) 21 Exercise
PLASMA SODIUM (UNC)
0d > Sigaudo et al. (1996) 4 None

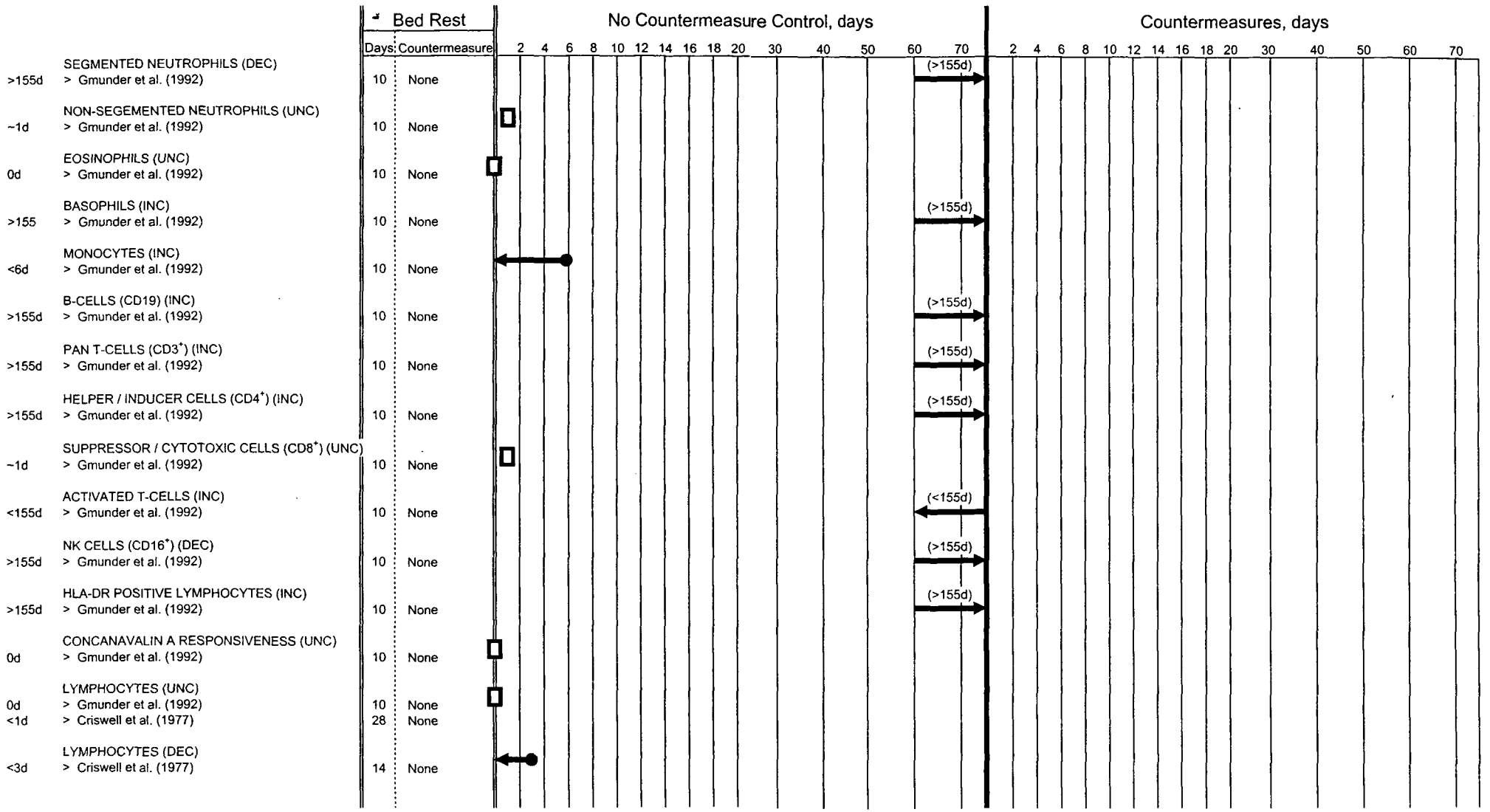

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
DAILY SODIUM BALANCE (DEC)
~1d > Vernikos et al. (1993) 7 None
SODIUM BALANCE (DEC)
<7d > Hyatt et al. (1975) 14 None
PLASMA POTASSIUM (UNC)
0d > Siguado et al. (1996) 4 None
0d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
BODY TOTAL POTASSIUM (DEC)
<7d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS
DAILY POTASSIUM BALANCE (INC)
~2d > Vernikos et al. (1993) 7 None
PLASMA OSMOLALITY (INC)
~3d > Greenleaf et al. (1977b) 14 None
~3d > Greenleaf et al. (1977b) 14 Exercise
PLASMA VISCOSITY (INC)
>14d > Martin et al. (1986) 10 None
PLASMA VISCOSITY (UNC)
>2d > Lampe et al. (1992) 10 None
PLASMA ALBUMIN (INC)
>14d > Martin et al. (1986) 10 None
PLASMA GLOBULIN (UNC)
0d > Martin et al. (1986) 10 None
PLASMA FIBRINOGEN (INC)
>14d > Martin et al. (1986) 10 None
SERUM SODIUM (INC)
<9d > Grigoryev et al. (1979) 27 None
SERUM POTASSIUM (DEC)
>9d > Grigoryev et al. (1979) 27 None
SERUM OSMOLALITY (INC)
2-9d > Grigoryev et al. (1979) 27 None
SERUM TOTAL CALCIUM (INC)
2-9d > Grigoryev et al. (1979) 27 None

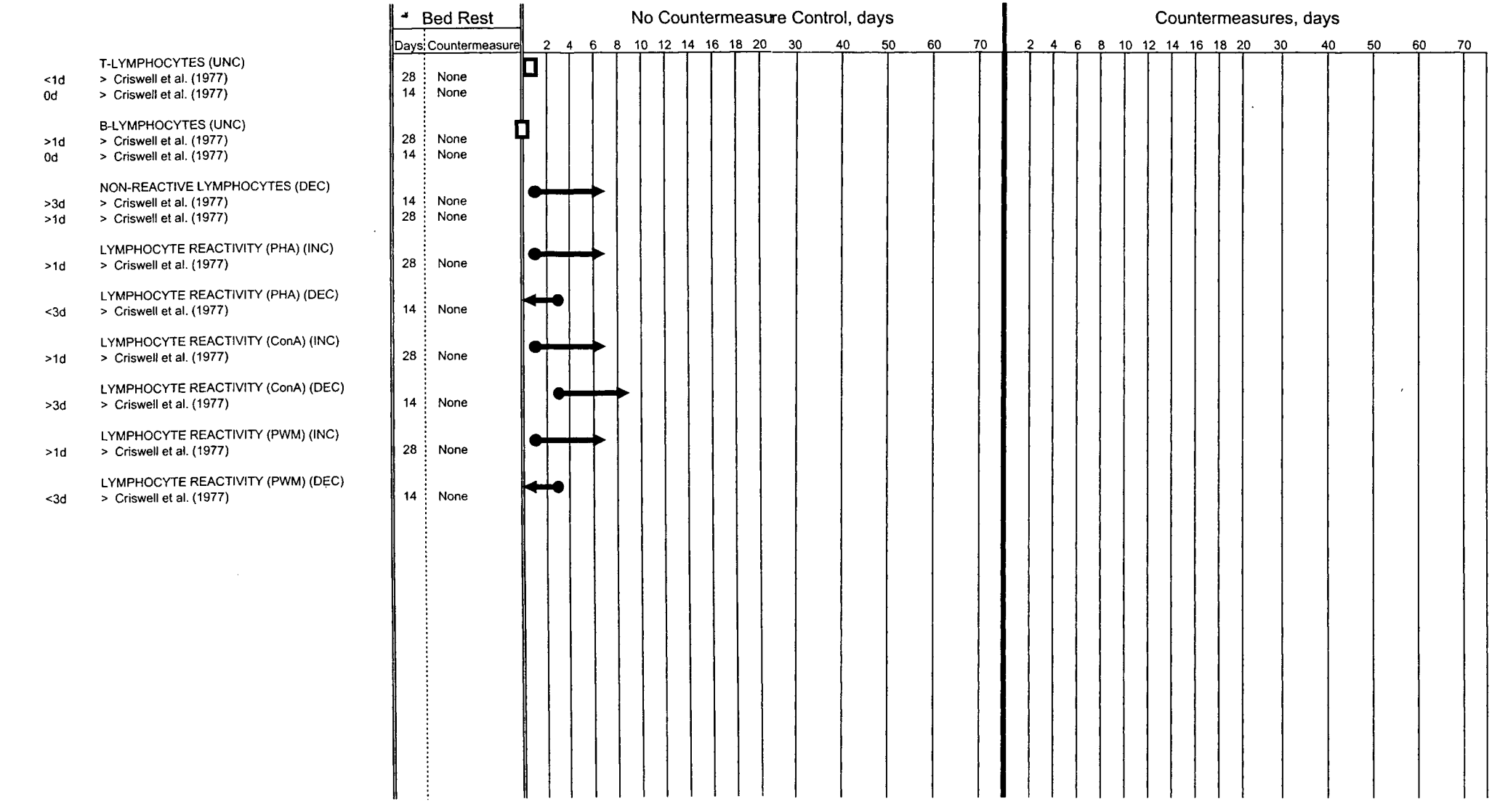

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
SERUM TOTAL CALCIUM (UNC)
0d > Arnaud et al. (1992) 7 None
SERUM IONIZED CALCIUM (INC)
<5d > Arnaud et al. (1992) 7 None
SERUM PHOSPHORUS (INC)
>5d > Arnaud et al. (1992) 7 None
SERUM PARATHYROID HORMONE (DEC)
<5d > Arnaud et al. (1992) 7 None
SERUM 1,25-DIHYDROXYVITAMIN D (DEC)
<5d > Arnaud et al. (1992) 7 None
SERUM CALCITONIN (DEC)
>5d > Arnaud et al. (1992) 7 None
PLASMA ARGININE VASOPRESSIN (INC)
0d > Maillet et al. (1995) 28 None
>3d > Maillet et al. (1995) (confinement) 28 None
PLASMA ARGININE VASOPRESSIN (UNC)
0d > Keil et al. (1976) 17 None
PLASMA RENIN ACTIVITY (INC)
~4d > Maillet et al. (1995) 28 None
>3d > Maillet et al. (1995) (confinement) 28 None
>5d > Gauquelin et al. (1996) 28 None
>2d > Guell et al. (1982) 7 None
>5d > Keil et al. (1976) 17 None
>28d > Fasola et al. (1970) 35 None
>28d > Fasola et al. (1970) 35 Exercise
PLASMA RENIN ACTIVITY (UNC)
0d > Vernikos et al. (1993) 7 None
PLASMA ALDOSTERONE (INC)
~4d > Maillet et al. (1995) 28 None
>3d > Maillet et al. (1995) (confinement) 28 None
>2d > Vernikos et al. (1993) 7 None
PLASMA ALDOSTERONE (UNC)
0d > Guell et al. (1982) 7 None
PLASMA ATRIAL NATRIURETIC PEPTIDE (DEC)
~3d > Sigaudo et al. (1996) 4 None
<5d > Gauquelin et al. (1996) 28 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
PLASMA ADRENOCORTICOTROPHIC HORMONE (UNC)
0d > Vernikos et al. (1993)
7 None
PLASMA CORTISOL (DEC)
>6d > Gmunder et al. (1992)
10 None
PLASMA CORTISOL (UNC)
0d > Vernikos et al. (1993)
7 None
PLASMA EPINEPHRINE (DEC)
>6d > Gmunder et al. (1992)
10 None
PLASMA NOREPINEPHRINE (DEC)
>6d > Gmunder et al. (1992)
10 None

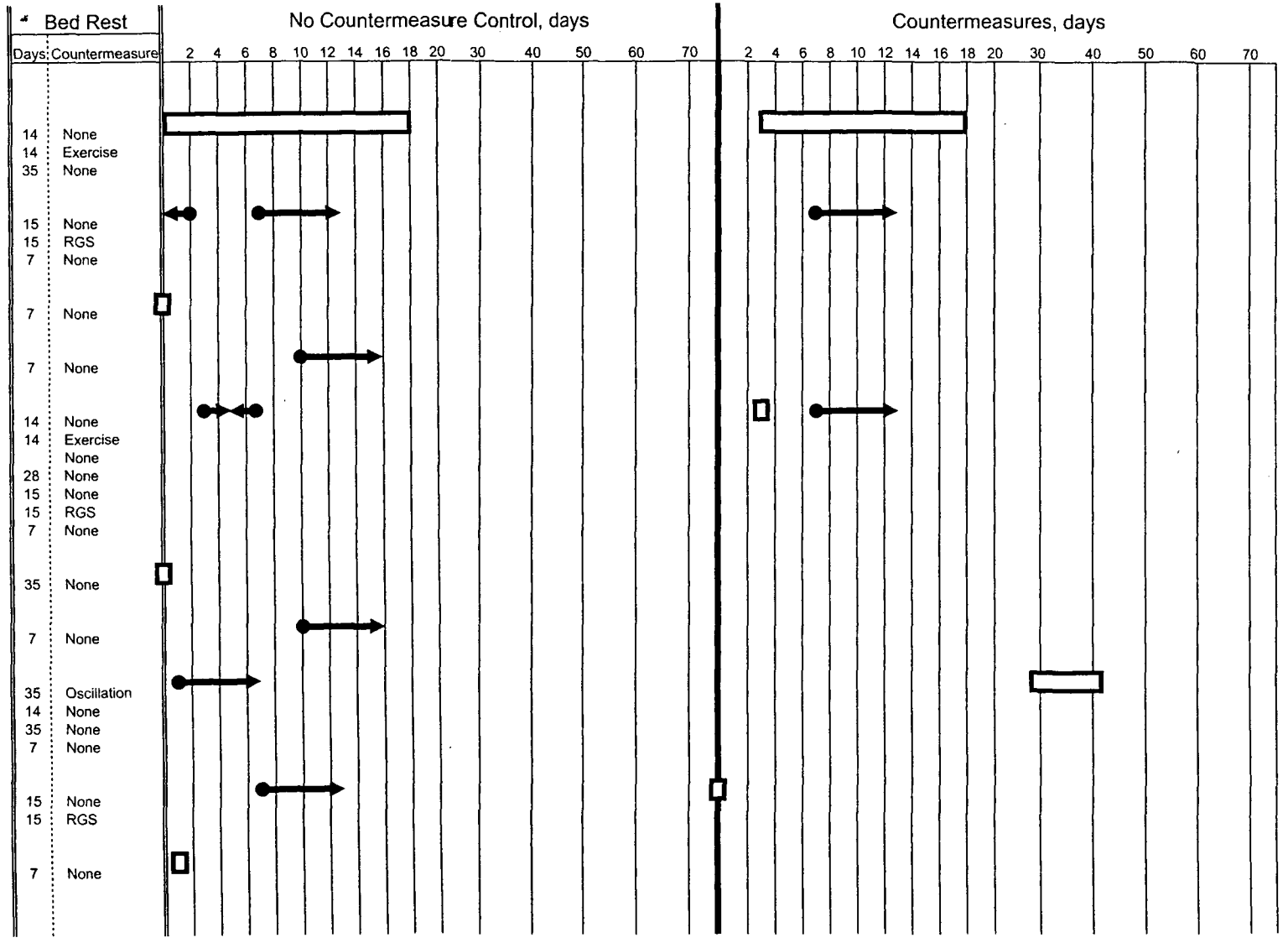

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days: Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2D. Cellular, Enzyme Variables
ORAL GLUCOSE TOLERANCE TEST (BLOOD GLUCOSE)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
ORAL GLUCOSE TOLERANCE TEST (BLOOD INSULIN)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
TOTAL LACTATE DEHYDROGENASE (DEC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
~1d > Greenleaf et al. (1985) 14 None
<3d > Greenleaf et al. (1985) 14 Exercise
LACTATE DEHYDROGENASE (LDH-1 + LDH-2) (DEC)
~1d > Greenleaf et al. (1985) 14 None
~1d > Greenleaf et al. (1985) 14 Exercise
LACTATE DEHYDROGENASE (LDH-3 + LDH-4 + LDH-5) (DEC)
~1d > Greenleaf et al. (1985) 14 None
<1d > Greenleaf et al. (1985) 14 Exercise
LACTATE DEHYDROGENASE -1 (DEC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
LACTATE DEHYDROGENASE -2 (DEC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
LACTATE DEHYDROGENASE -3 (DEC)
~7d > Sandler et al. (1983) 15 None
~7d > Sandler et al. (1983) 15 RGS
LACTATE DEHYDROGENASE -4 (UNC)
0d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS
LACTATE DEHYDROGENASE -5 (INC)
<7d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days: Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
ALKALINE PHOSPHATASE (DEC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
SERUM GLUTAMIC OXALOACETIC TRANSAMINASE (INC)
<7d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS
PLATELET ALPHA 2 - RECEPTOR DENSITY (INC)
~3d > Maass et al. (1992) 10 None
LYMPHOCYTE BETA 2 - RECEPTOR DENSITY (INC)
>155d > Maass et al. (1992) 10 None
LYMPHOCYTE BETA 2 - RECEPTOR RESPONSIVENESS (UNC)
0d > Maass et al. (1992) 10 None
MEAN CORPUSCULAR VOLUME (DEC)
<2d > Lampe et al. (1992) 10 None
MEAN CORPUSCULAR HEMOGLOBIN (UNC)
0d > Lampe et al. (1992) 10 None
MEAN CORPUSCULAR HEMOGLOBIN CONCENTRATION (INC)
<2d > Lampe et al. (1992) 10 None
WHITE BLOOD CELLS (INC)
>3d > Criswell et al. (1977) 14 None
>1d > Criswell et al. (1977) 28 None
WHITE BLOOD CELLS (DEC)
<155d > Gmunder et al. (1992) 10 None
(<155d)
LYMPHOCYTE RESPONSE (UNC)
0d > Gmunder et al. (1992) 10 None
DELAYED-TYPE HYPERSENSITIVITY (DEC)
<6d > Gmunder et al. (1992) 10 None
NEUTROPHILS (UNC)
~1d > Gmunder et al. (1992) 10 None

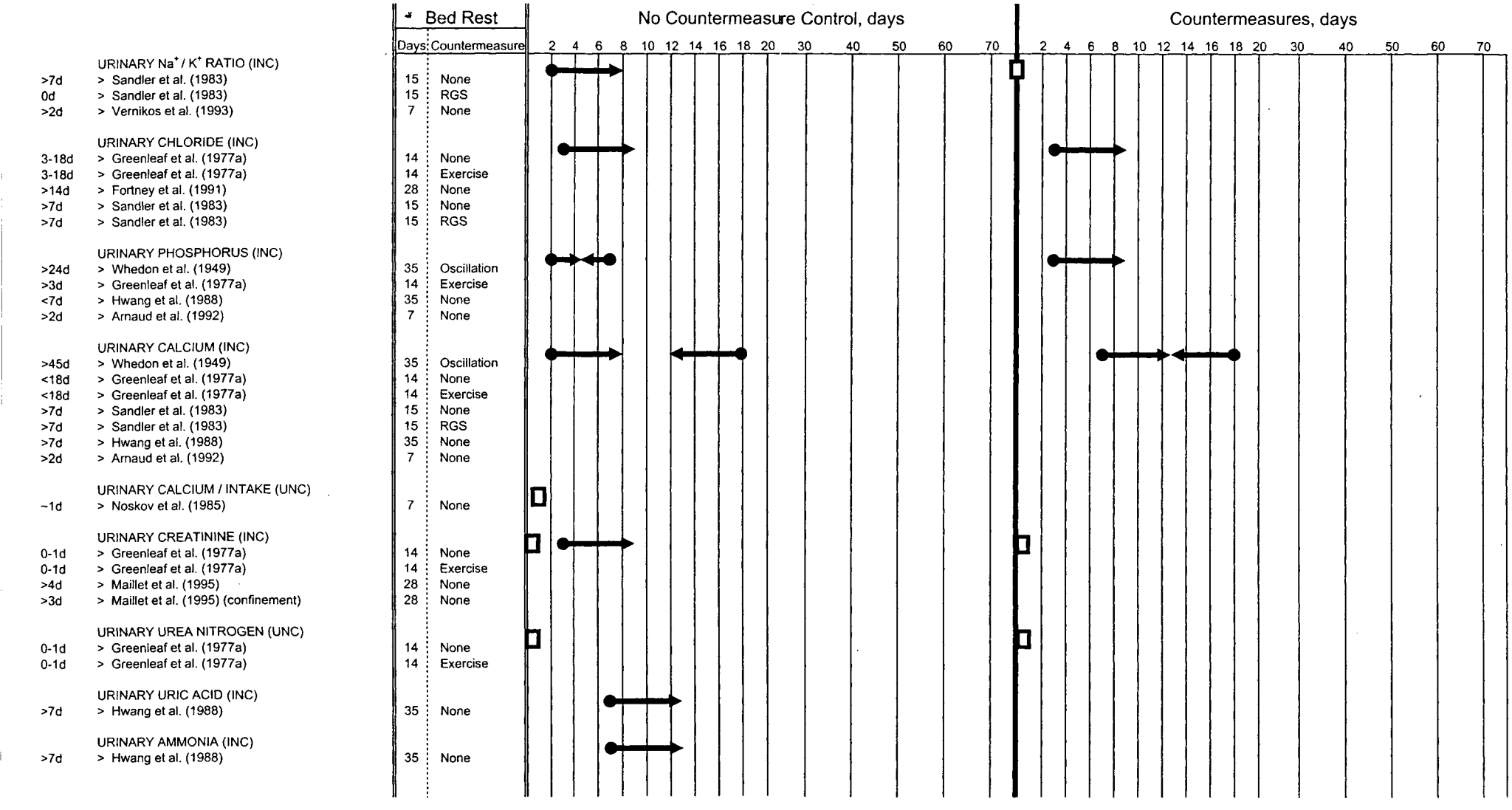

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
SEGMENTED NEUTROPHILS (DEC)
>155d > Gmunder et al. (1992) 10 None (>155d)
NON-SEGEMENTED NEUTROPHILS (UNC)
~1d > Gmunder et al. (1992) 10 None
EOSINOPHILS (UNC)
0d > Gmunder et al. (1992) 10 None
BASOPHILS (INC)
>155 > Gmunder et al. (1992) 10 None (>155d)
MONOCYTES (INC)
<6d > Gmunder et al. (1992) 10 None
B-CELLS (CD19) (INC)
>155d > Gmunder et al. (1992) 10 None (>155d)
PAN T-CELLS (CD3+) (INC)
>155d > Gmunder et al. (1992) 10 None (>155d)
HELPER / INDUCER CELLS (CD4+) (INC)
>155d > Gmunder et al. (1992) 10 None (>155d)
SUPPRESSOR / CYTOTOXIC CELLS (CD8+) (UNC)
~1d > Gmunder et al. (1992) 10 None
ACTIVATED T-CELLS (INC)
<155d > Gmunder et al. (1992) 10 None (<155d)
NK CELLS (CD16+) (DEC)
>155d > Gmunder et al. (1992) 10 None (>155d)
HLA-DR POSITIVE LYMPHOCYTES (INC)
>155d > Gmunder et al. (1992) 10 None (>155d)
CONCANAVALIN A RESPONSIVENESS (UNC)
0d > Gmunder et al. (1992) 10 None
LYMPHOCYTES (UNC)
0d > Gmunder et al. (1992) 10 None
<1d > Criswell et al. (1977) 28 None
LYMPHOCYTES (DEC)
<3d > Criswell et al. (1977) 14 None

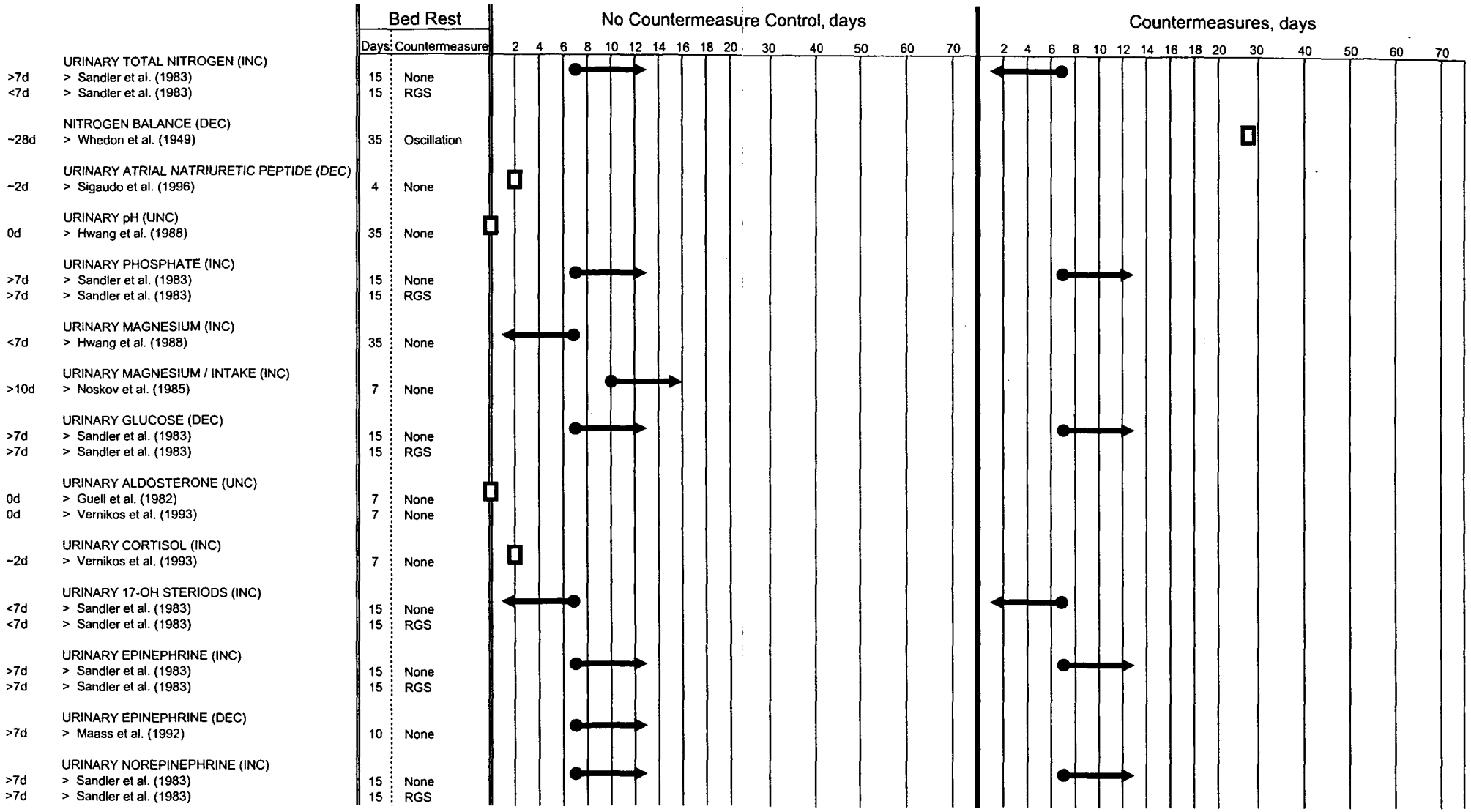

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
T-LYMPHOCYTES (UNC)
<1d > Criswell et al. (1977) 28 None
0d > Criswell et al. (1977) 14 None
B-LYMPHOCYTES (UNC)
>1d > Criswell et al. (1977) 28 None
0d > Criswell et al. (1977) 14 None
NON-REACTIVE LYMPHOCYTES (DEC)
>3d > Criswell et al. (1977) 14 None
>1d > Criswell et al. (1977) 28 None
LYMPHOCYTE REACTIVITY (PHA) (INC)
>1d > Criswell et al. (1977) 28 None
LYMPHOCYTE REACTIVITY (PHA) (DEC)
<3d > Criswell et al. (1977) 14 None
LYMPHOCYTE REACTIVITY (ConA) (INC)
>1d > Criswell et al. (1977) 28 None
LYMPHOCYTE REACTIVITY (ConA) (DEC)
>3d > Criswell et al. (1977) 14 None
LYMPHOCYTE REACTIVITY (PWM) (INC)
>1d > Criswell et al. (1977) 28 None
LYMPHOCYTE REACTIVITY (PWM) (DEC)
<3d > Criswell et al. (1977) 14 None

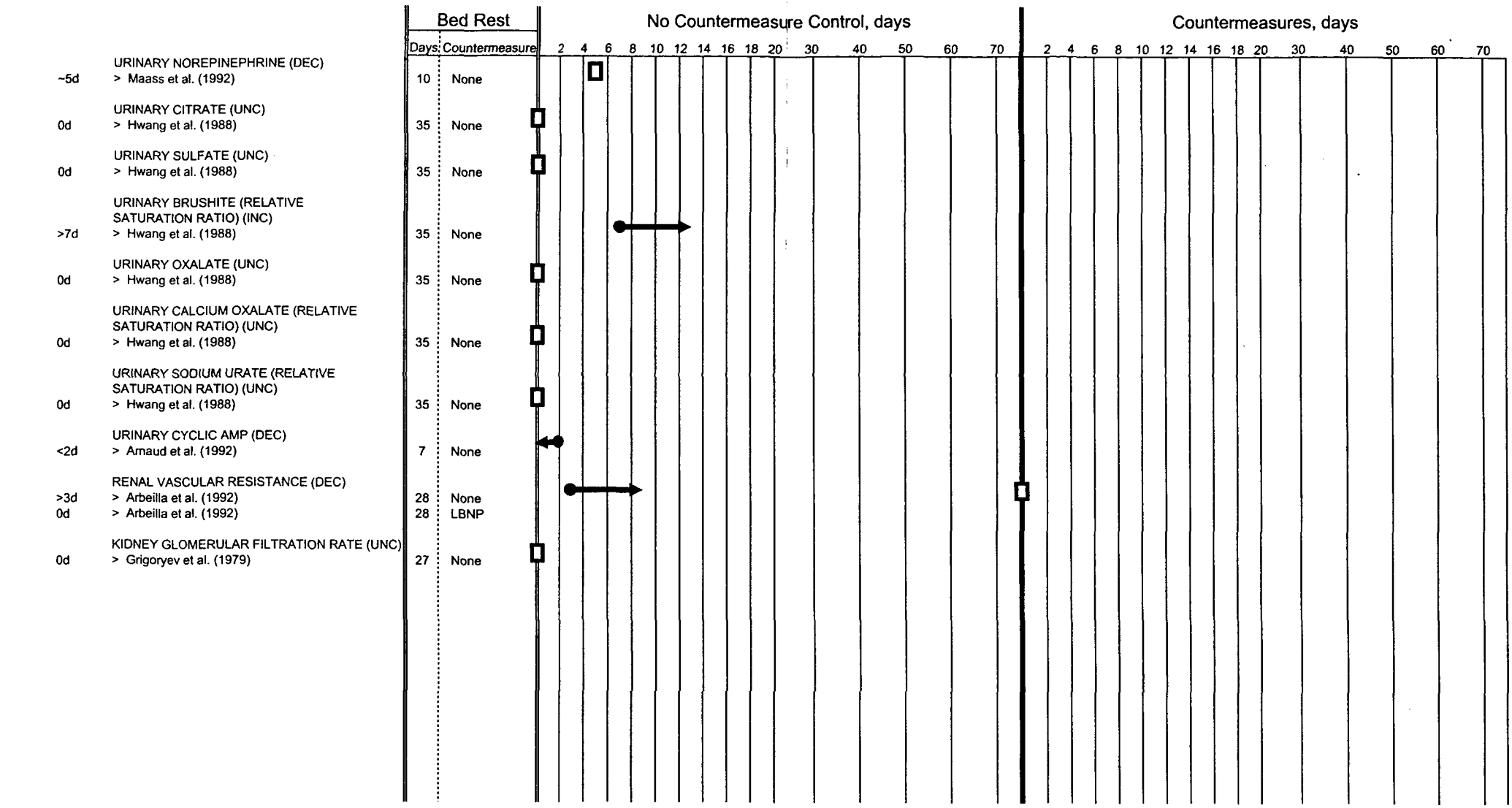
2E. Urinary-Renal Variables

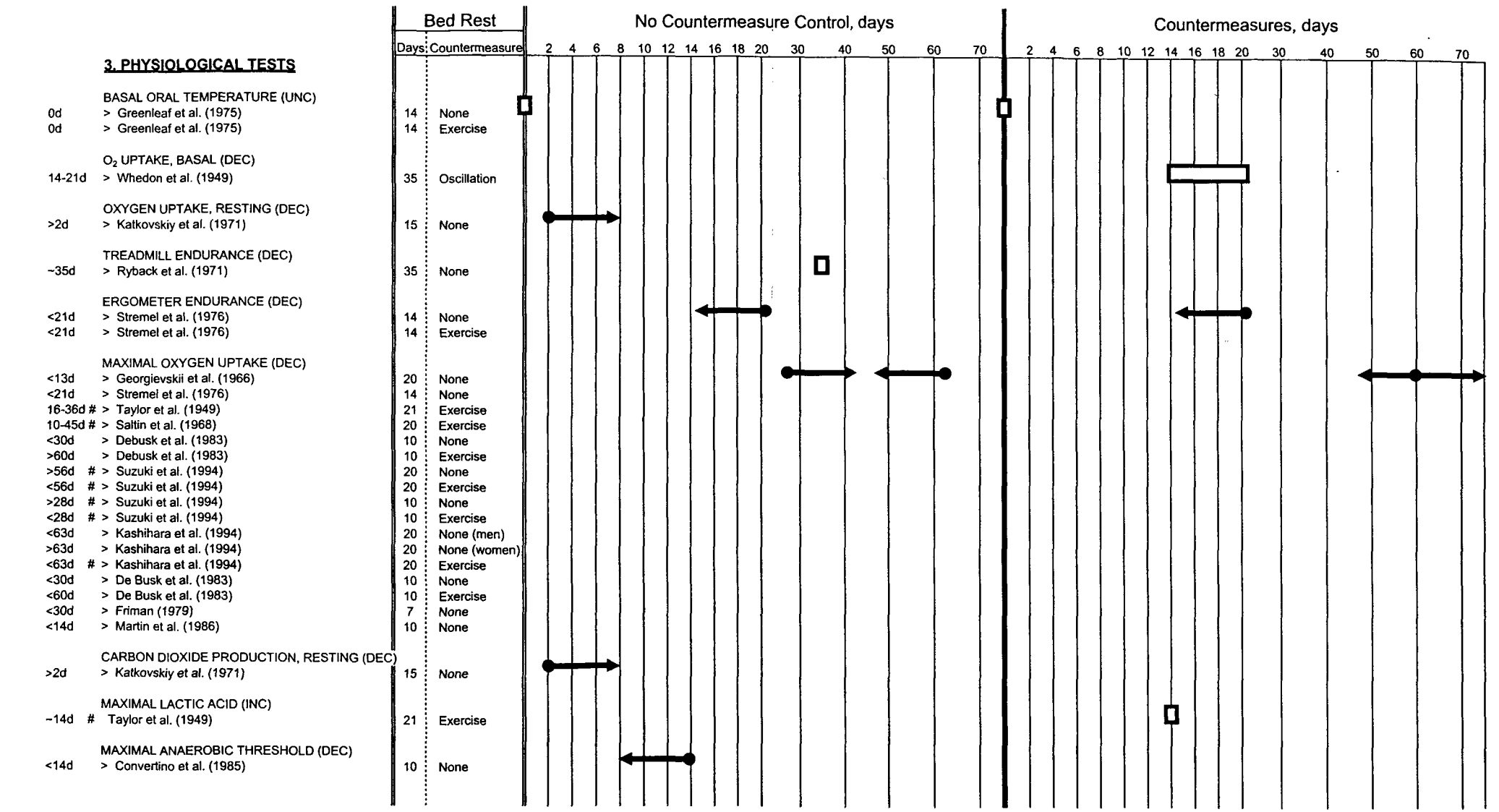


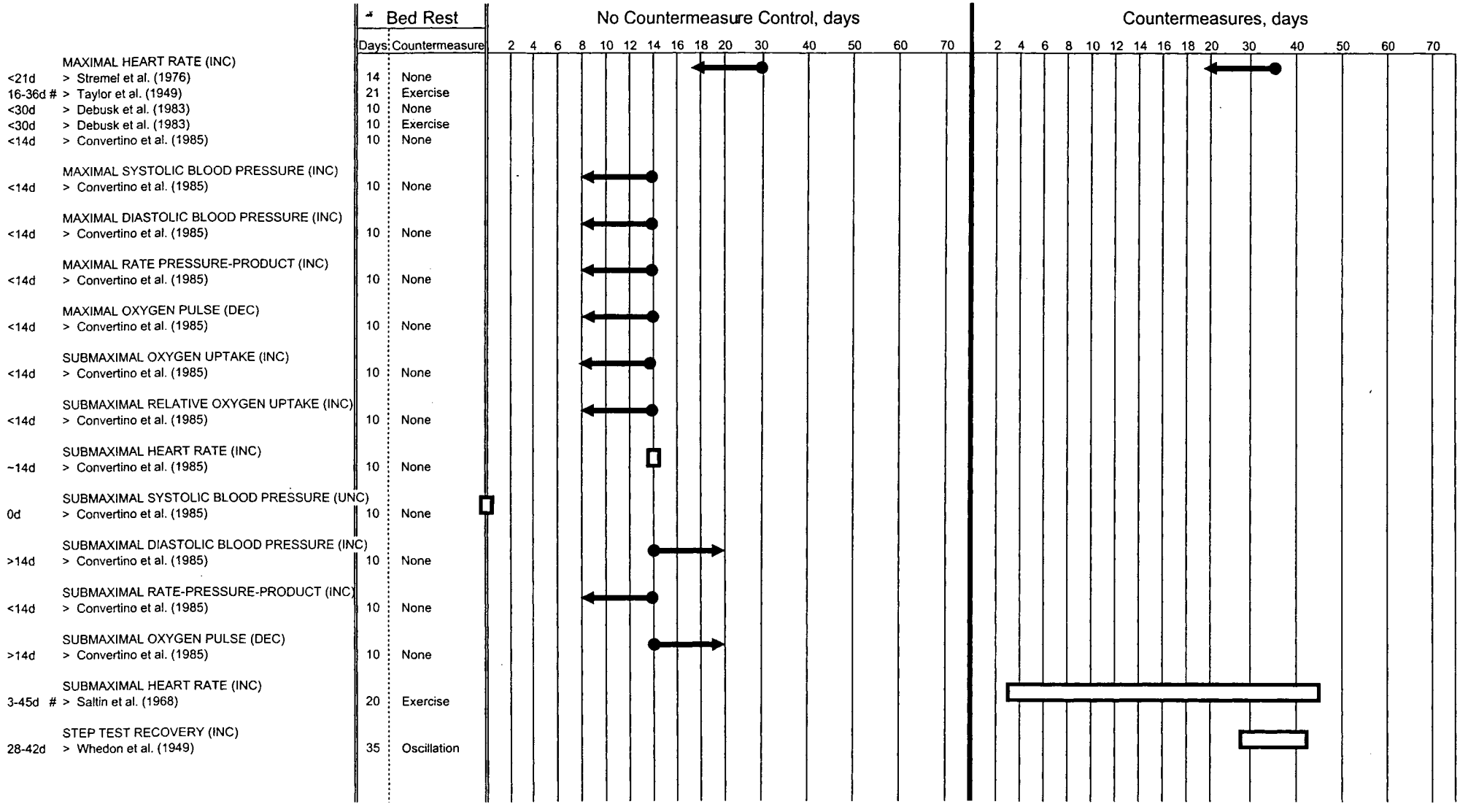
	URINARY VOLUME (INC)		
3-18d	> Greenleaf et al. (1977a)	14	None
3-18d	> Greenleaf et al. (1977a)	14	Exercise
<7d	> Hwang et al. (1988)	35	None
	URINARY VOLUME (DEC)		
>7d	> Sandler et al. (1983)	15	None
>7d	> *Sandler et al.* (1983)	15	RGS
<2d	> Arnaud et al. (1992)	7	None
	URINARY VOLUME (UNC)		
0d	> Guell et al. (1982)	7	None
	URINARY VOLUME / INTAKE (INC)		
>10d	> Noskov et al. (1985)	7	None
	URINARY SODIUM (INC)		
~3d	> Greenleaf et al. (1977a)	14	None
~3d	> Greenleaf et al. (1977a)	14	Exercise
>3d	> *Maillet et al.* (1995)		None
>14d	> Fortney et al. (1991)	28	None
<7d	> Sandler et al. (1983)	15	None
>7d	> Sandler et al. (1983)	15	RGS
<2d	> Arnaud et al. (1992)	7	None
	URINARY SODIUM (UNC)		
0d	> Hwang et al. (1988)	35	None
	URINARY SODIUM / INTAKE (DEC)		
>10d	> Noskov et al. (1985)	7	None
	URINARY POTASSIUM (INC)		
28-42d	> Whedon et al. (1949)	35	Oscillation
~1d	> Greenleaf et al. (1977a)	14	None
>7d	> Hwang et al. (1988)	35	None
~1d	> Arnaud et al. (1992)	7	None
	URINARY POTASSIUM (DEC)		
>7d	> *Sandler et al.* (1983)	15	None
0d	> Sandler et al. (1983)	15	RGS
	URINARY POTASSIUM / INTAKE (INC)		
~1d	> Noskov et al. (1985)	7	None

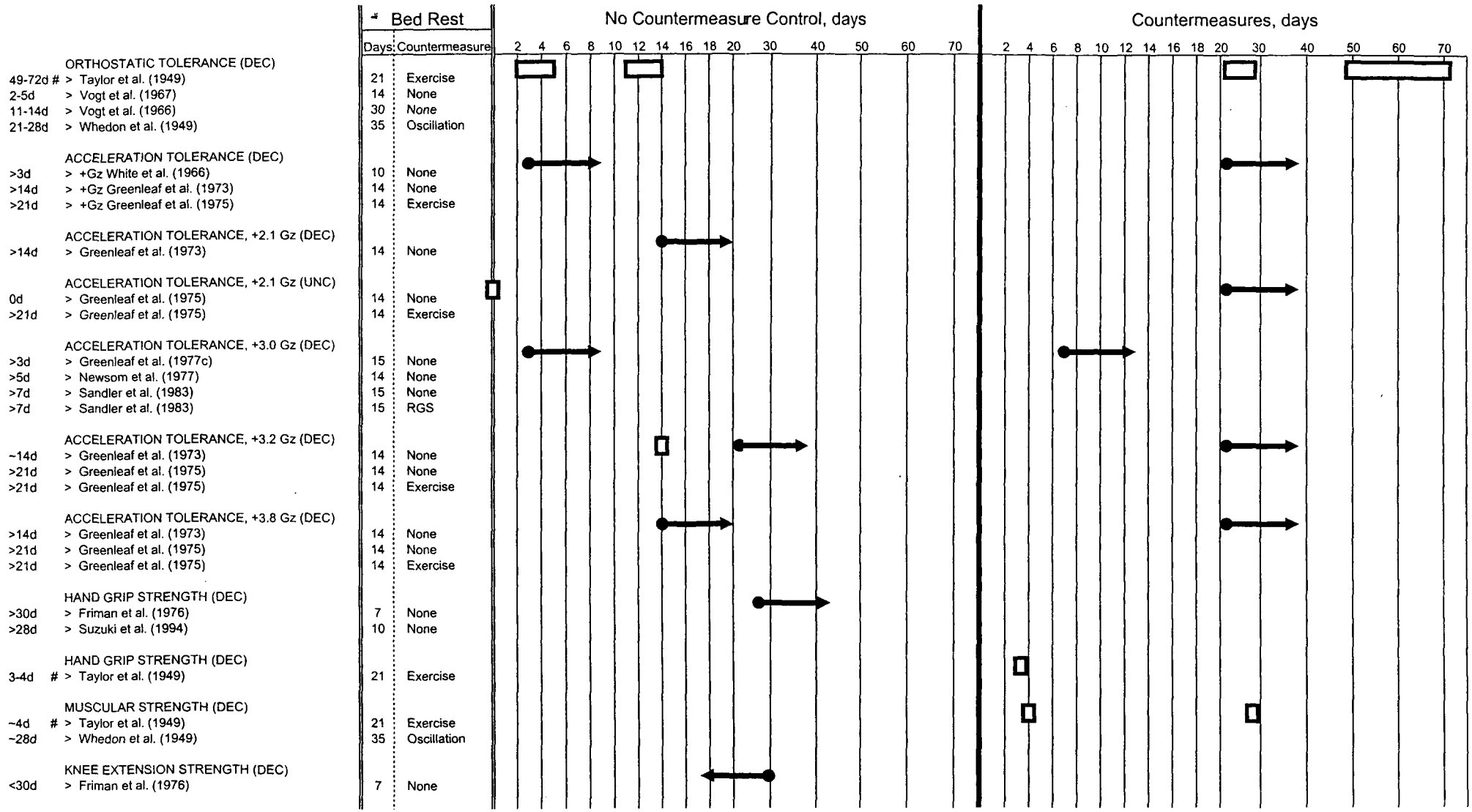

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
URINARY Na+ / K+ RATIO (INC)
>7d > Sandler et al. (1983) 15 None
0d > Sandler et al. (1983) 15 RGS
>2d > Vernikos et al. (1993) 7 None
URINARY CHLORIDE (INC)
3-18d > Greenleaf et al. (1977a) 14 None
3-18d > Greenleaf et al. (1977a) 14 Exercise
>14d > Fortney et al. (1991) 28 None
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
URINARY PHOSPHORUS (INC)
>24d > Whedon et al. (1949) 35 Oscillation
>3d > Greenleaf et al. (1977a) 14 Exercise
<7d > Hwang et al. (1988) 35 None
>2d > Arnaud et al. (1992) 7 None
URINARY CALCIUM (INC)
>45d > Whedon et al. (1949) 35 Oscillation
<18d > Greenleaf et al. (1977a) 14 None
<18d > Greenleaf et al. (1977a) 14 Exercise
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
>7d > Hwang et al. (1988) 35 None
>2d > Arnaud et al. (1992) 7 None
URINARY CALCIUM / INTAKE (UNC)
~1d > Noskov et al. (1985) 7 None
URINARY CREATININE (INC)
0-1d > Greenleaf et al. (1977a) 14 None
0-1d > Greenleaf et al. (1977a) 14 Exercise
>4d > Maillet et al. (1995) 28 None
>3d > Maillet et al. (1995) (confinement) 28 None
URINARY UREA NITROGEN (UNC)
0-1d > Greenleaf et al. (1977a) 14 None
0-1d > Greenleaf et al. (1977a) 14 Exercise
URINARY URIC ACID (INC)
>7d > Hwang et al. (1988) 35 None
URINARY AMMONIA (INC)
>7d > Hwang et al. (1988) 35 None

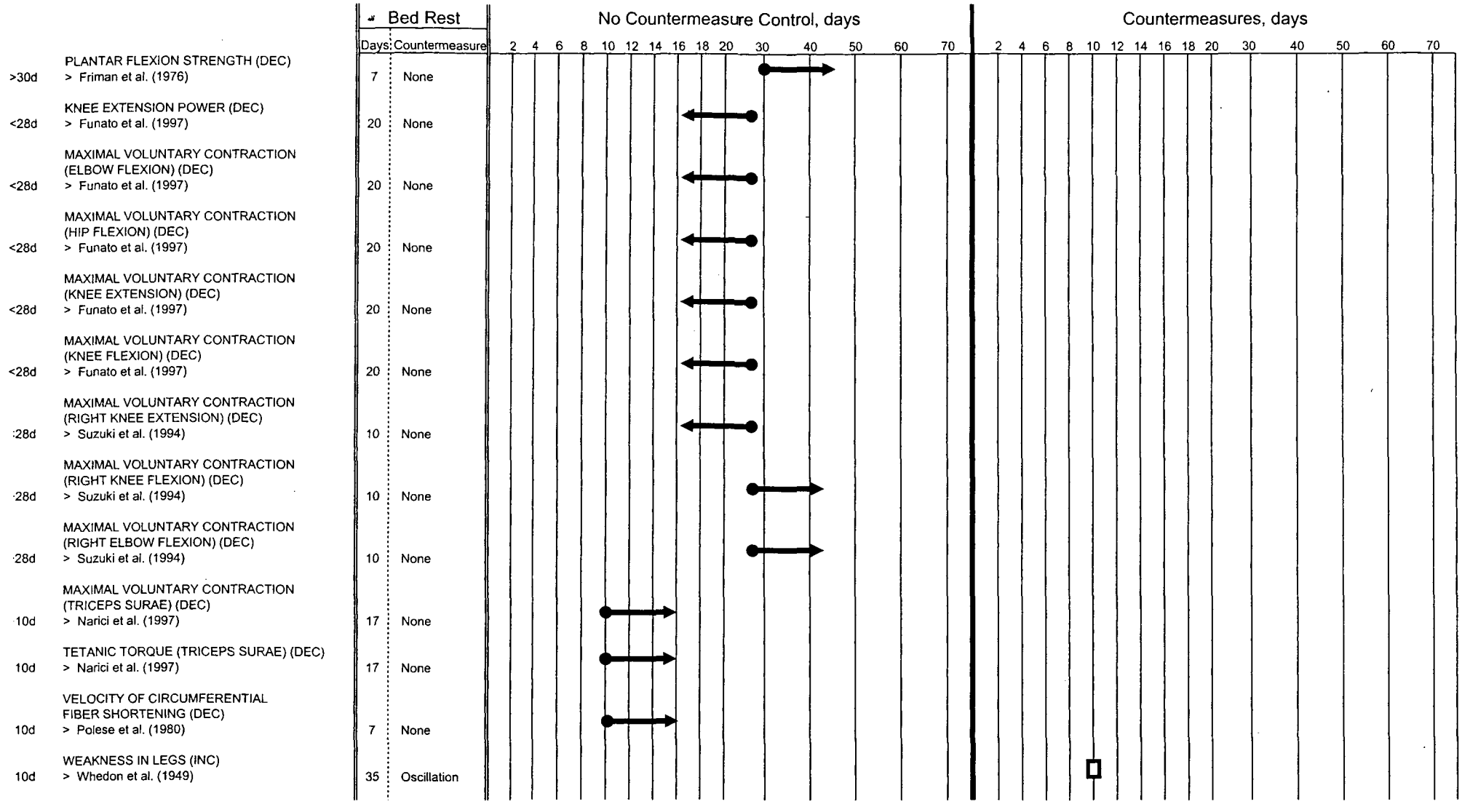

Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
URINARY TOTAL NITROGEN (INC)
>7d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS
NITROGEN BALANCE (DEC)
~28d > Whedon et al. (1949) 35 Oscillation
URINARY ATRIAL NATRIURETIC PEPTIDE (DEC)
~2d > Sigaudo et al. (1996) 4 None
URINARY pH (UNC)
0d > Hwang et al. (1988) 35 None
URINARY PHOSPHATE (INC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
URINARY MAGNESIUM (INC)
<7d > Hwang et al. (1988) 35 None
URINARY MAGNESIUM / INTAKE (INC)
>10d > Noskov et al. (1985) 7 None
URINARY GLUCOSE (DEC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
URINARY ALDOSTERONE (UNC)
0d > Guell et al. (1982) 7 None
0d > Vernikos et al. (1993) 7 None
URINARY CORTISOL (INC)
~2d > Vernikos et al. (1993) 7 None
URINARY 17-OH STERIODS (INC)
<7d > Sandler et al. (1983) 15 None
<7d > Sandler et al. (1983) 15 RGS
URINARY EPINEPHRINE (INC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
URINARY EPINEPHRINE (DEC)
>7d > Maass et al. (1992) 10 None
URINARY NOREPINEPHRINE (INC)
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS

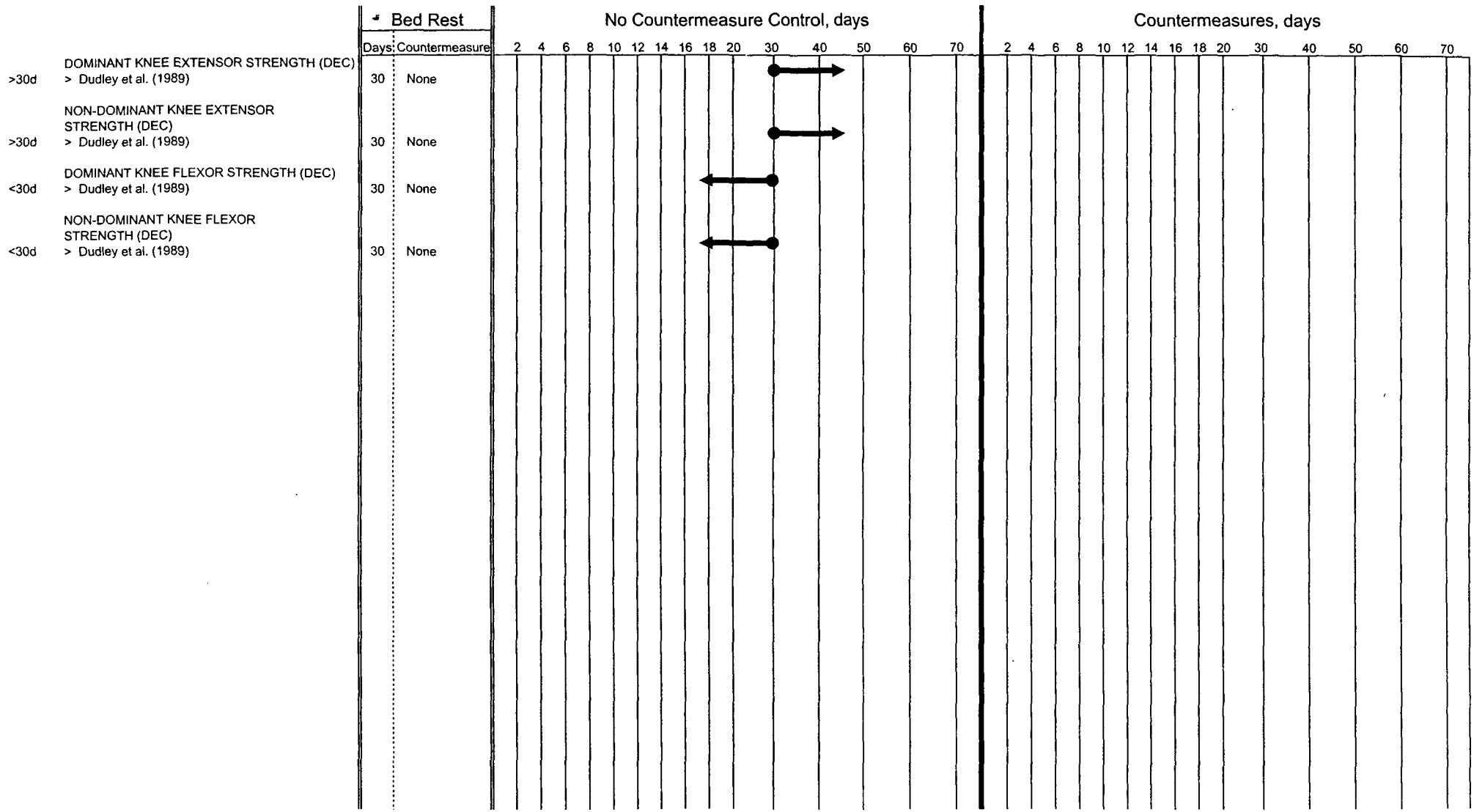

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
URINARY NOREPINEPHRINE (DEC)
~5d > Maass et al. (1992) 10 None
URINARY CITRATE (UNC)
0d > Hwang et al. (1988) 35 None
URINARY SULFATE (UNC)
0d > Hwang et al. (1988) 35 None
URINARY BRUSHITE (RELATIVE SATURATION RATIO) (INC)
>7d > Hwang et al. (1988) 35 None
URINARY OXALATE (UNC)
0d > Hwang et al. (1988) 35 None
URINARY CALCIUM OXALATE (RELATIVE SATURATION RATIO) (UNC)
0d > Hwang et al. (1988) 35 None
URINARY SODIUM URATE (RELATIVE SATURATION RATIO) (UNC)
0d > Hwang et al. (1988) 35 None
URINARY CYCLIC AMP (DEC)
<2d > Arnaud et al. (1992) 7 None
RENAL VASCULAR RESISTANCE (DEC)
>3d > Arbeilla et al. (1992) 28 None
0d > Arbeilla et al. (1992) 28 LBNP
KIDNEY GLOMERULAR FILTRATION RATE (UNC)
0d > Grigoryev et al. (1979) 27 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days: Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
3. PHYSIOLOGICAL TESTS
BASAL ORAL TEMPERATURE (UNC)
0d > Greenleaf et al. (1975) 14 None
0d > Greenleaf et al. (1975) 14 Exercise
O2 UPTAKE, BASAL (DEC)
14-21d > Whedon et al. (1949) 35 Oscillation
OXYGEN UPTAKE, RESTING (DEC)
>2d > Katkovskiy et al. (1971) 15 None
TREADMILL ENDURANCE (DEC)
~35d > Ryback et al. (1971) 35 None
ERGOMETER ENDURANCE (DEC)
<21d > Stremel et al. (1976) 14 None
<21d > Stremel et al. (1976) 14 Exercise
MAXIMAL OXYGEN UPTAKE (DEC)
<13d > Georgievskii et al. (1966) 20 None
<21d > Stremel et al. (1976) 14 None
16-36d # > Taylor et al. (1949) 21 Exercise
10-45d # > Saltin et al. (1968) 20 Exercise
<30d > Debusk et al. (1983) 10 None
>60d > Debusk et al. (1983) 10 Exercise
>56d # > Suzuki et al. (1994) 20 None
<56d # > Suzuki et al. (1994) 20 Exercise
>28d # > Suzuki et al. (1994) 10 None
<28d # > Suzuki et al. (1994) 10 Exercise
<63d > Kashihara et al. (1994) 20 None (men)
>63d > Kashihara et al. (1994) 20 None (women)
<63d # > Kashihara et al. (1994) 20 Exercise
<30d > De Busk et al. (1983) 10 None
<60d > De Busk et al. (1983) 10 Exercise
<30d > Friman (1979) 7 None
<14d > Martin et al. (1986) 10 None
CARBON DIOXIDE PRODUCTION, RESTING (DEC)
>2d > Katkovskiy et al. (1971) 15 None
MAXIMAL LACTIC ACID (INC)
~14d # Taylor et al. (1949) 21 Exercise
MAXIMAL ANAEROBIC THRESHOLD (DEC)
<14d > Convertino et al. (1985) 10 None

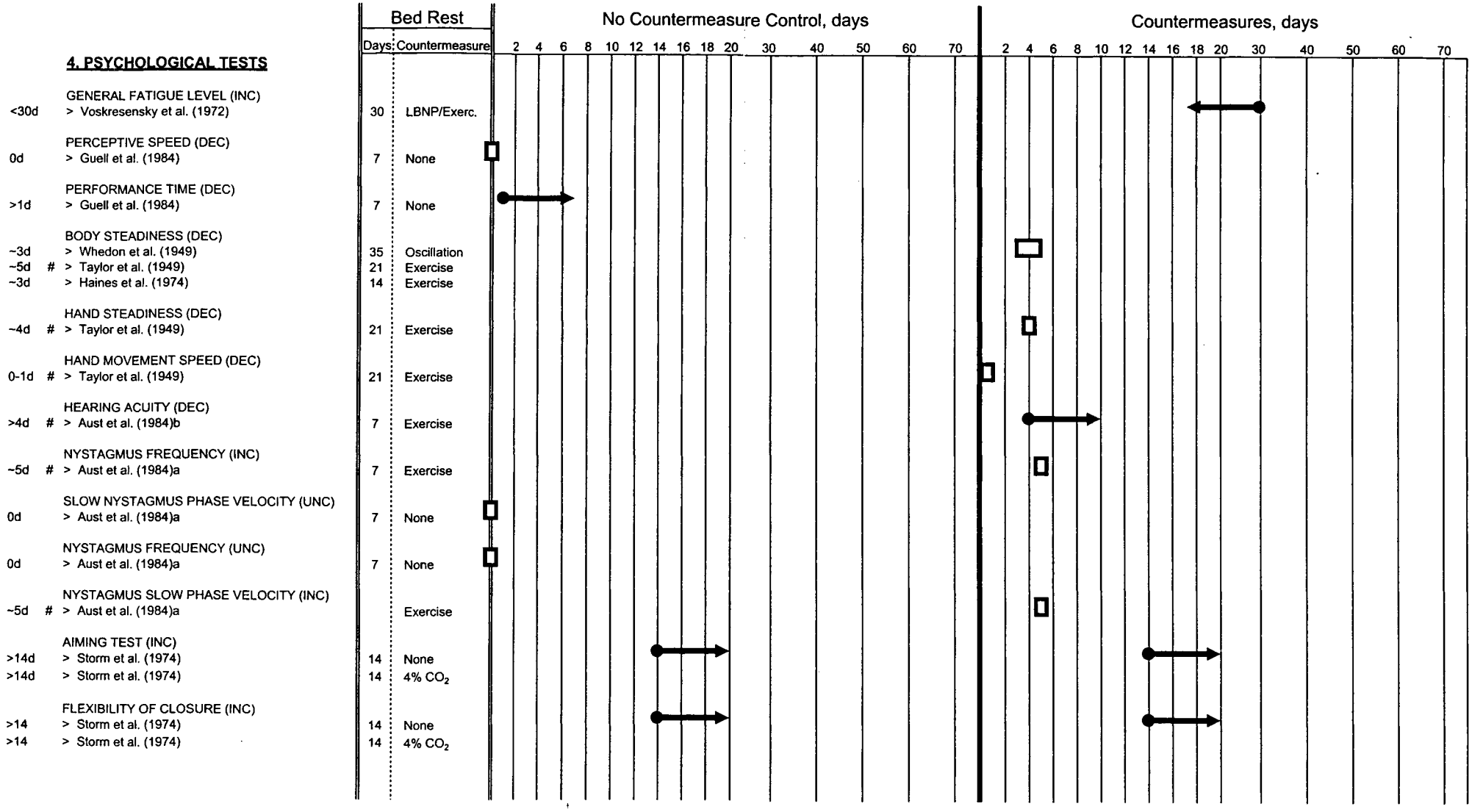

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
MAXIMAL HEART RATE (INC)
<21d > Stremel et al. (1976) 14 None
16-36d # > Taylor et al. (1949) 21 Exercise
<30d > Debusk et al. (1983) 10 None
<30d > Debusk et al. (1983) 10 Exercise
<14d > Convertino et al. (1985) 10 None
MAXIMAL SYSTOLIC BLOOD PRESSURE (INC)
<14d > Convertino et al. (1985) 10 None
MAXIMAL DIASTOLIC BLOOD PRESSURE (INC)
<14d > Convertino et al. (1985) 10 None
MAXIMAL RATE PRESSURE-PRODUCT (INC)
<14d > Convertino et al. (1985) 10 None
MAXIMAL OXYGEN PULSE (DEC)
<14d > Convertino et al. (1985) 10 None
SUBMAXIMAL OXYGEN UPTAKE (INC)
<14d > Convertino et al. (1985) 10 None
SUBMAXIMAL RELATIVE OXYGEN UPTAKE (INC)
<14d > Convertino et al. (1985) 10 None
SUBMAXIMAL HEART RATE (INC)
~14d > Convertino et al. (1985) 10 None
SUBMAXIMAL SYSTOLIC BLOOD PRESSURE (UNC)
0d > Convertino et al. (1985) 10 None
SUBMAXIMAL DIASTOLIC BLOOD PRESSURE (INC)
>14d > Convertino et al. (1985) 10 None
SUBMAXIMAL RATE-PRESSURE-PRODUCT (INC)
<14d > Convertino et al. (1985) 10 None
SUBMAXIMAL OXYGEN PULSE (DEC)
>14d > Convertino et al. (1985) 10 None
SUBMAXIMAL HEART RATE (INC)
3-45d # > Saltin et al. (1968) 20 Exercise
STEP TEST RECOVERY (INC)
28-42d > Whedon et al. (1949) 35 Oscillation

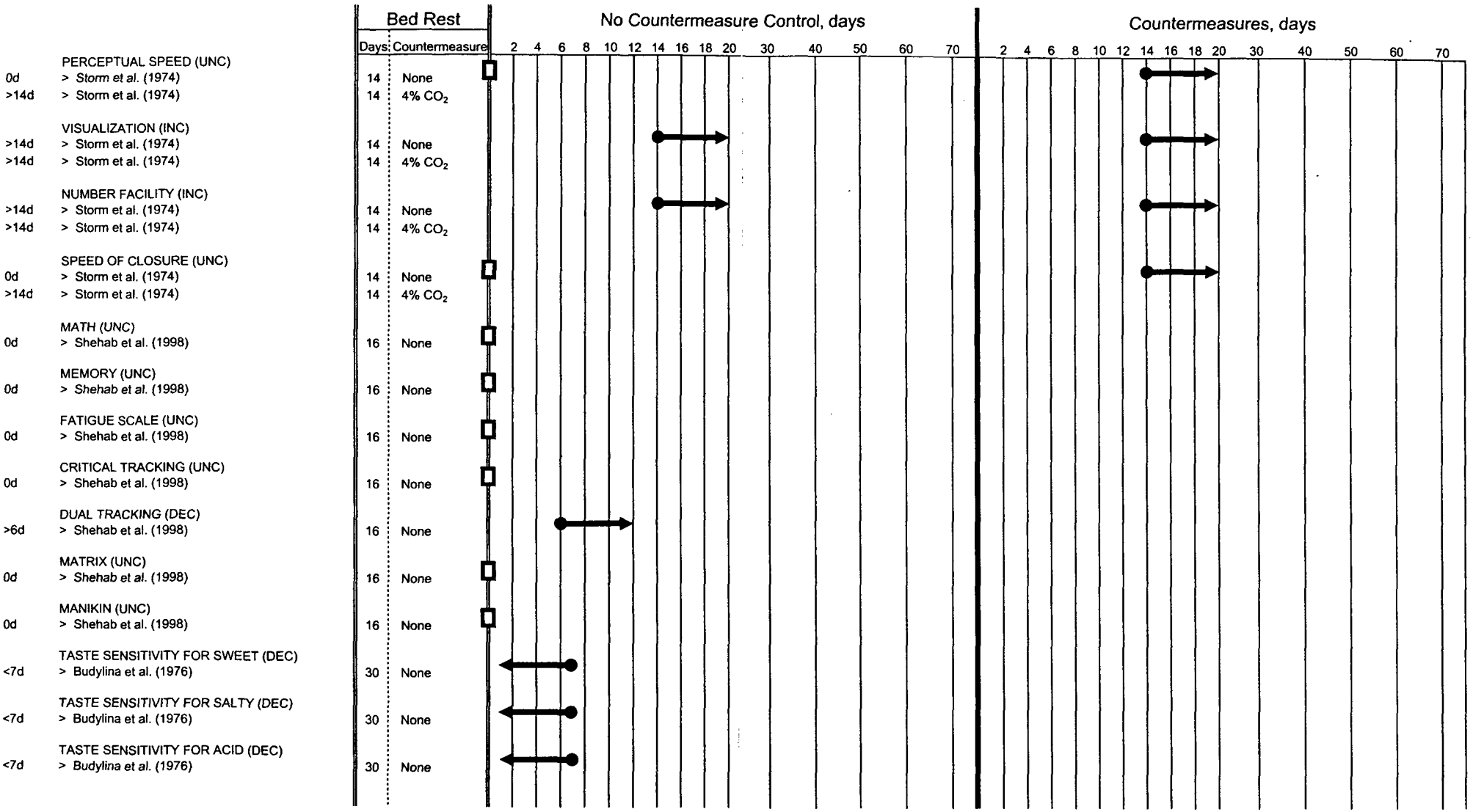

Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
ORTHOSTATIC TOLERANCE (DEC)
49-72d # > Taylor et al. (1949) 21 Exercise
2-5d > Vogt et al. (1967) 14 None
11-14d > Vogt et al. (1966) 30 None
21-28d > Whedon et al. (1949) 35 Oscillation
ACCELERATION TOLERANCE (DEC)
>3d > +Gz White et al. (1966) 10 None
>14d > +Gz Greenleaf et al. (1973) 14 None
>21d > +Gz Greenleaf et al. (1975) 14 Exercise
ACCELERATION TOLERANCE, +2.1 Gz (DEC)
>14d > Greenleaf et al. (1973) 14 None
ACCELERATION TOLERANCE, +2.1 Gz (UNC)
0d > Greenleaf et al. (1975) 14 None
>21d > Greenleaf et al. (1975) 14 Exercise
ACCELERATION TOLERANCE, +3.0 Gz (DEC)
>3d > Greenleaf et al. (1977c) 15 None
>5d > Newsom et al. (1977) 14 None
>7d > Sandler et al. (1983) 15 None
>7d > Sandler et al. (1983) 15 RGS
ACCELERATION TOLERANCE, +3.2 Gz (DEC)
~14d > Greenleaf et al. (1973) 14 None
>21d > Greenleaf et al. (1975) 14 None
>21d > Greenleaf et al. (1975) 14 Exercise
ACCELERATION TOLERANCE, +3.8 Gz (DEC)
>14d > Greenleaf et al. (1973) 14 None
>21d > Greenleaf et al. (1975) 14 None
>21d > Greenleaf et al. (1975) 14 Exercise
HAND GRIP STRENGTH (DEC)
>30d > Friman et al. (1976) 7 None
>28d > Suzuki et al. (1994) 10 None
HAND GRIP STRENGTH (DEC)
3-4d # > Taylor et al. (1949) 21 Exercise
MUSCULAR STRENGTH (DEC)
~4d # > Taylor et al. (1949) 21 Exercise
~28d > Whedon et al. (1949) 35 Oscillation
KNEE EXTENSION STRENGTH (DEC)
<30d > Friman et al. (1976) 7 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days: Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
PLANTAR FLEXION STRENGTH (DEC)
>30d > Friman et al. (1976) 7 None
KNEE EXTENSION POWER (DEC)
<28d > Funato et al. (1997) 20 None
MAXIMAL VOLUNTARY CONTRACTION (ELBOW FLEXION) (DEC)
<28d > Funato et al. (1997) 20 None
MAXIMAL VOLUNTARY CONTRACTION (HIP FLEXION) (DEC)
<28d > Funato et al. (1997) 20 None
MAXIMAL VOLUNTARY CONTRACTION (KNEE EXTENSION) (DEC)
<28d > Funato et al. (1997) 20 None
MAXIMAL VOLUNTARY CONTRACTION (KNEE FLEXION) (DEC)
<28d > Funato et al. (1997) 20 None
MAXIMAL VOLUNTARY CONTRACTION (RIGHT KNEE EXTENSION) (DEC)
:28d > Suzuki et al. (1994) 10 None
MAXIMAL VOLUNTARY CONTRACTION (RIGHT KNEE FLEXION) (DEC)
·28d > Suzuki et al. (1994) 10 None
MAXIMAL VOLUNTARY CONTRACTION (RIGHT ELBOW FLEXION) (DEC)
·28d > Suzuki et al. (1994) 10 None
MAXIMAL VOLUNTARY CONTRACTION (TRICEPS SURAE) (DEC)
·10d > Narici et al. (1997) 17 None
TETANIC TORQUE (TRICEPS SURAE) (DEC)
10d > Narici et al. (1997) 17 None
VELOCITY OF CIRCUMFERENTIAL FIBER SHORTENING (DEC)
10d > Polese et al. (1980) 7 None
WEAKNESS IN LEGS (INC)
10d > Whedon et al. (1949) 35 Oscillation


Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
DOMINANT KNEE EXTENSOR STRENGTH (DEC)
>30d > Dudley et al. (1989) 30 None
NON-DOMINANT KNEE EXTENSOR STRENGTH (DEC)
>30d > Dudley et al. (1989) 30 None
DOMINANT KNEE FLEXOR STRENGTH (DEC)
<30d > Dudley et al. (1989) 30 None
NON-DOMINANT KNEE FLEXOR STRENGTH (DEC)
<30d > Dudley et al. (1989) 30 None

4. PSYCHOLOGICAL TESTS




Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
PERCEPTUAL SPEED (UNC)
0d > Storm et al. (1974) 14 None
>14d > Storm et al. (1974) 14 4% CO2
VISUALIZATION (INC)
>14d > Storm et al. (1974) 14 None
>14d > Storm et al. (1974) 14 4% CO2
NUMBER FACILITY (INC)
>14d > Storm et al. (1974) 14 None
>14d > Storm et al. (1974) 14 4% CO2
SPEED OF CLOSURE (UNC)
0d > Storm et al. (1974) 14 None
>14d > Storm et al. (1974) 14 4% CO2
MATH (UNC)
0d > Shehab et al. (1998) 16 None
MEMORY (UNC)
0d > Shehab et al. (1998) 16 None
FATIGUE SCALE (UNC)
0d > Shehab et al. (1998) 16 None
CRITICAL TRACKING (UNC)
0d > Shehab et al. (1998) 16 None
DUAL TRACKING (DEC)
>6d > Shehab et al. (1998) 16 None
MATRIX (UNC)
0d > Shehab et al. (1998) 16 None
MANIKIN (UNC)
0d > Shehab et al. (1998) 16 None
TASTE SENSITIVITY FOR SWEET (DEC)
<7d > Budylina et al. (1976) 30 None
TASTE SENSITIVITY FOR SALTY (DEC)
<7d > Budylina et al. (1976) 30 None
TASTE SENSITIVITY FOR ACID (DEC)
<7d > Budylina et al. (1976) 30 None

TASTE SENSITIVITY FOR BITTER (DEC)

<7d > Budylina et al. (1976)

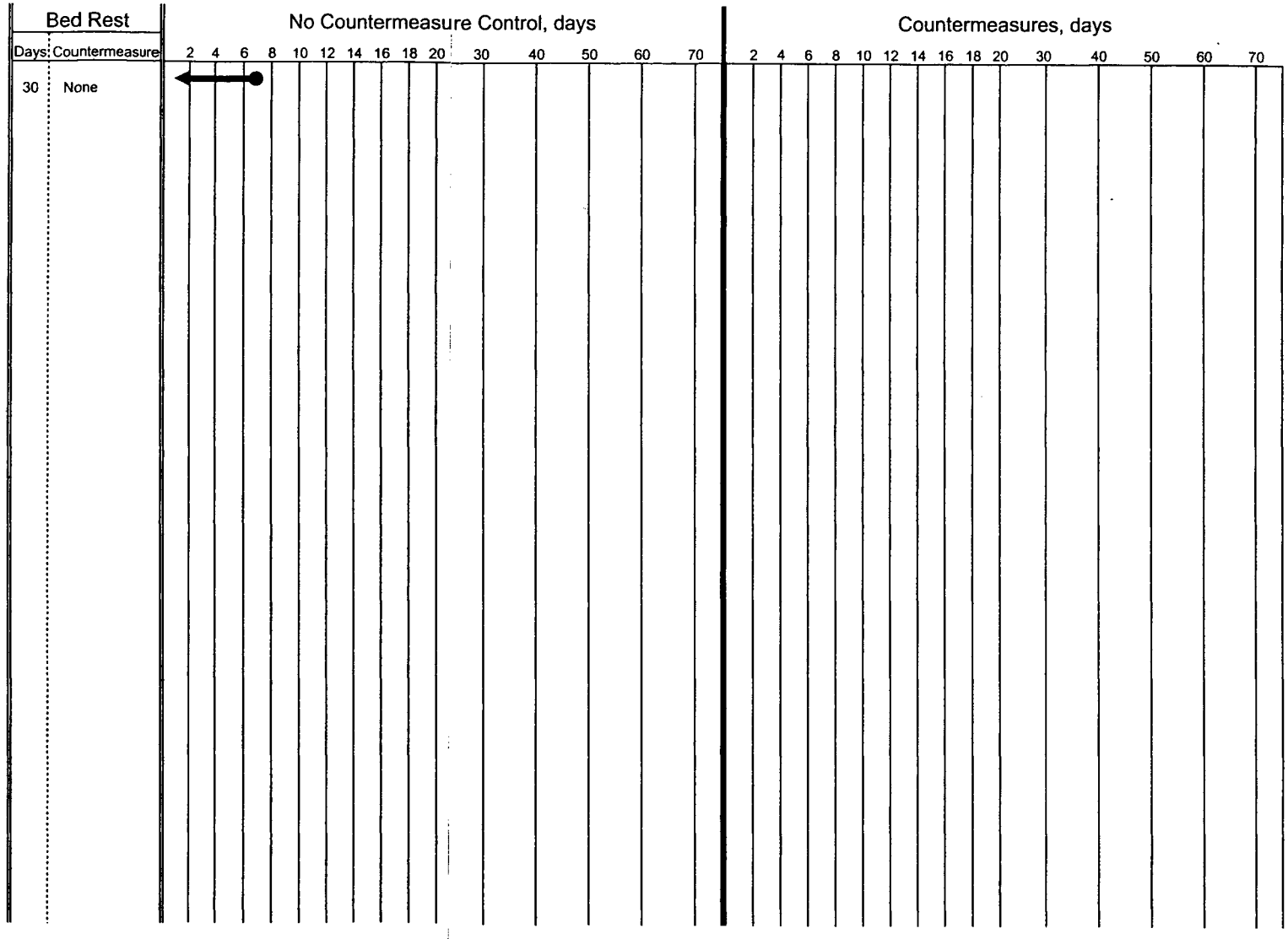
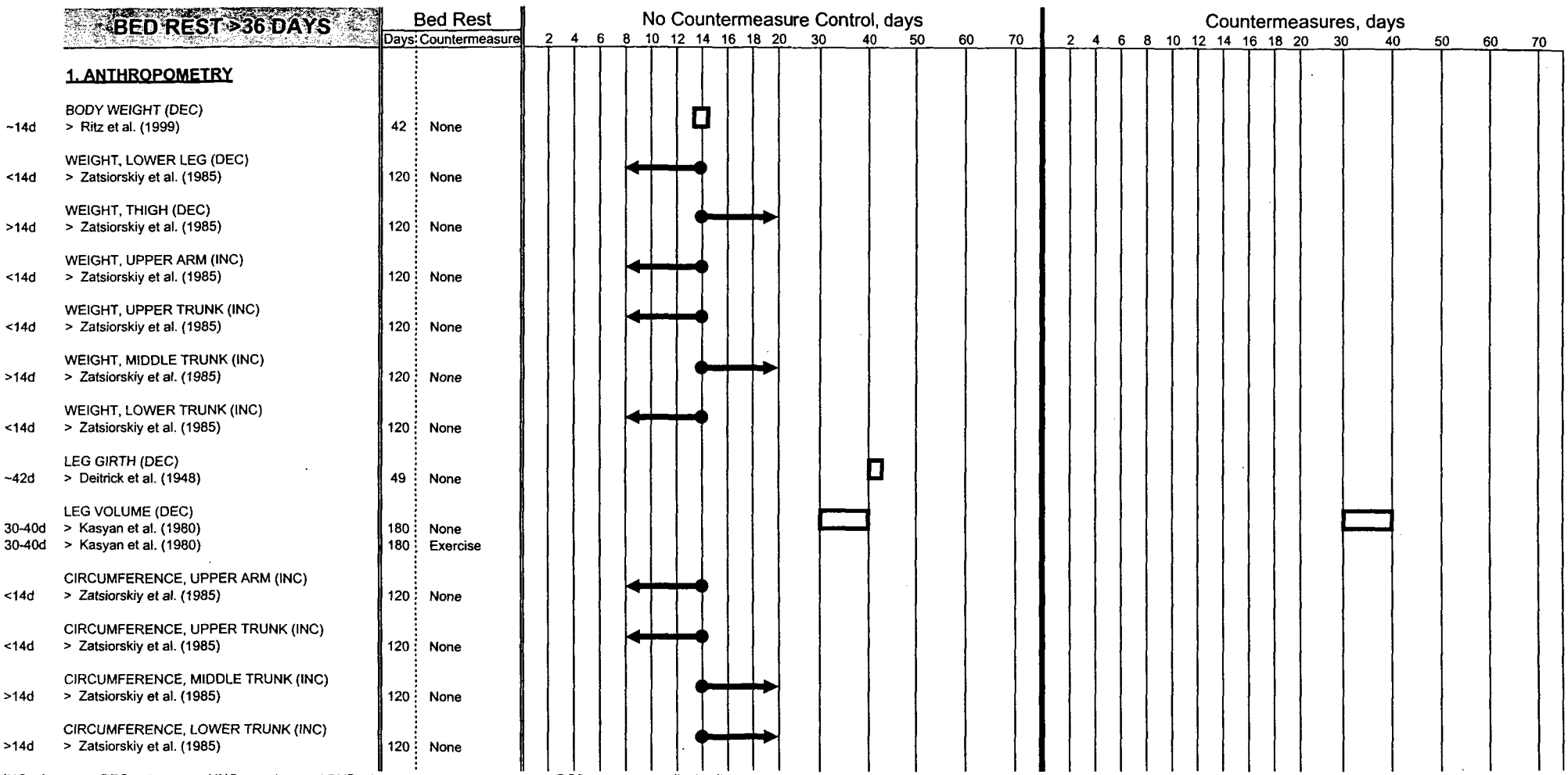
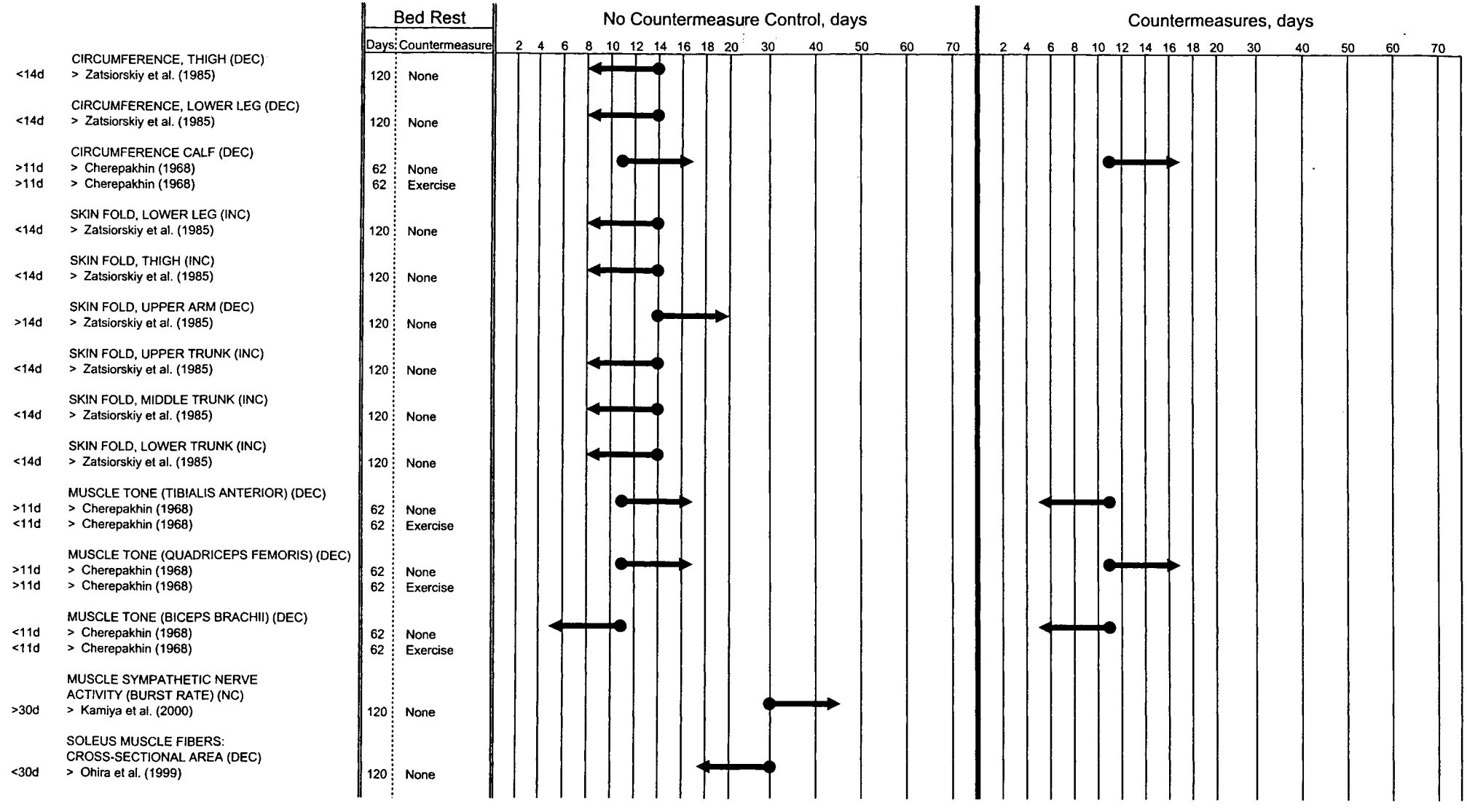
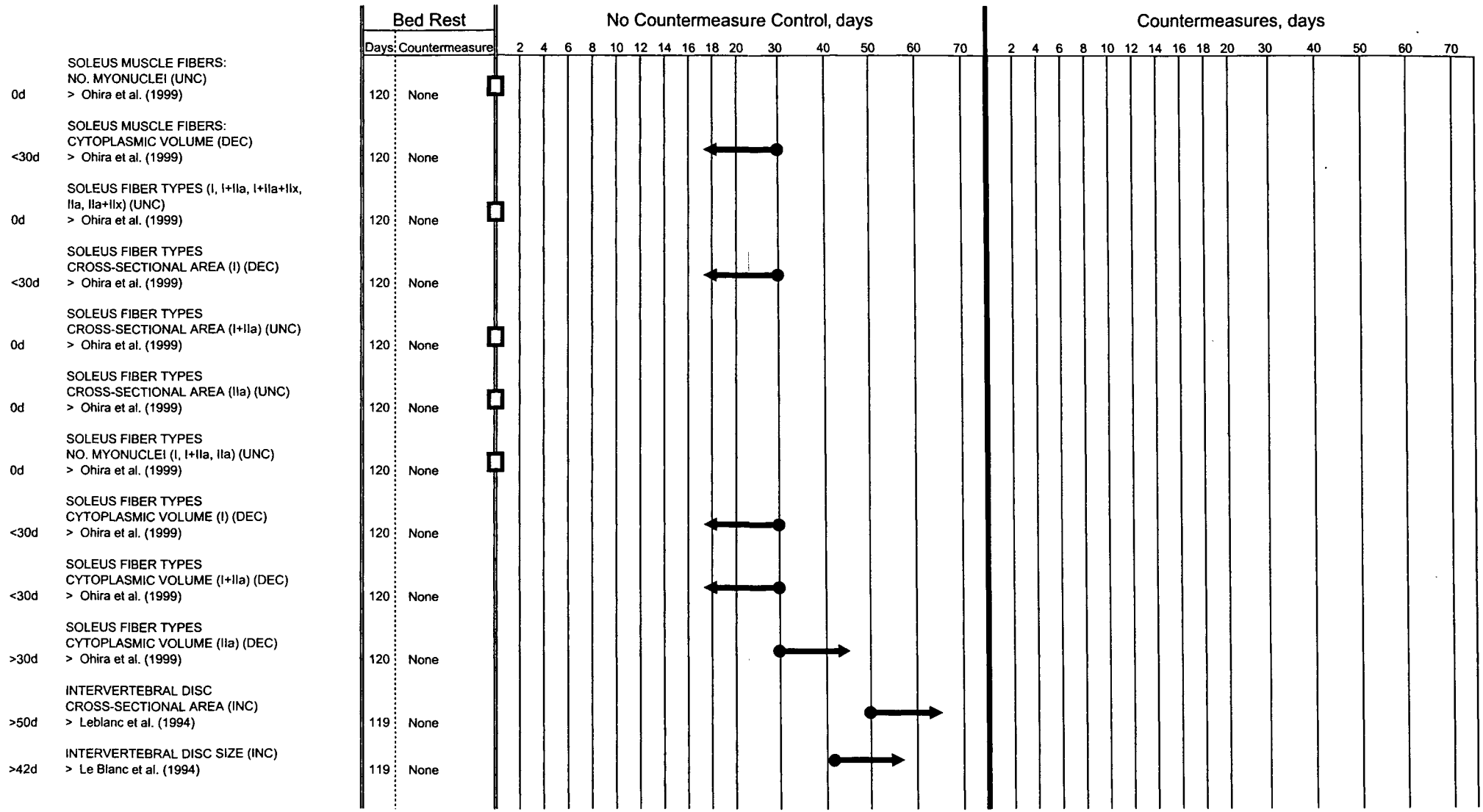


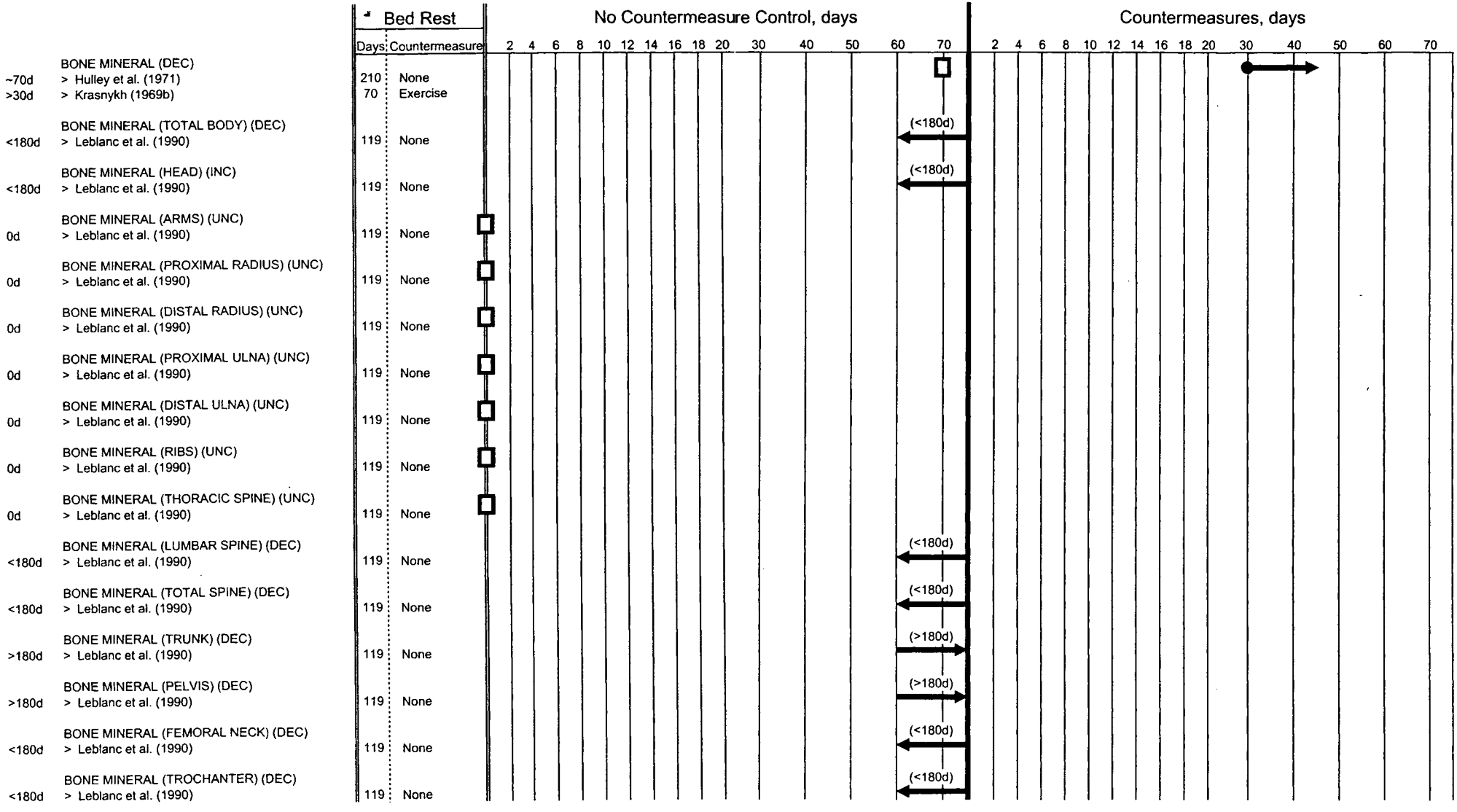
Figure 2. Recovery data for bed-rest periods greater than 36 days.

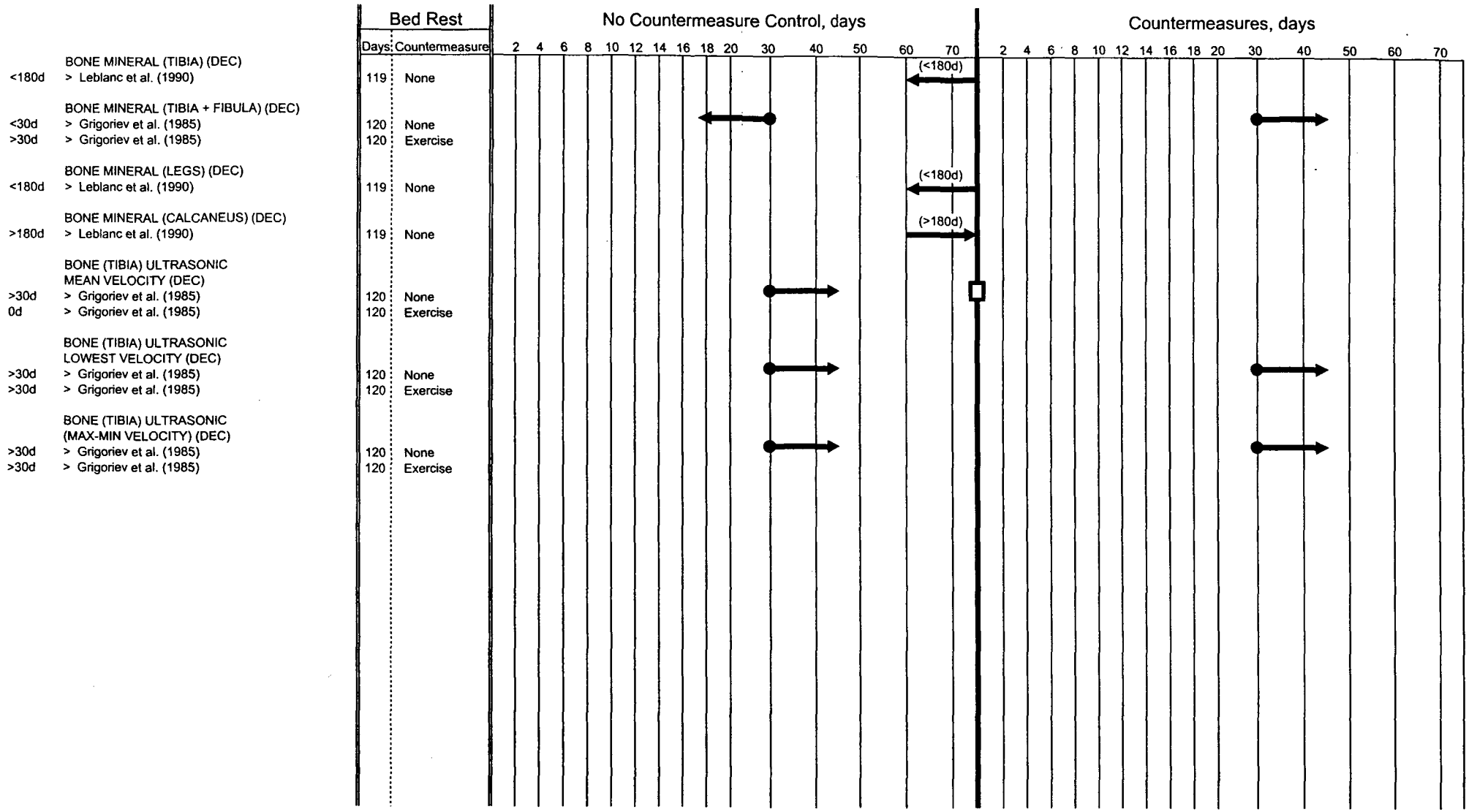


INC = increase; DEC = decrease; UNC = unchange; LBNP = lower body negative pressure; RGS = reverse gradient suit;
# = countermeasure done during Recovery period; HUT = head up tilt


Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
CIRCUMFERENCE, THIGH (DEC)
<14d > Zatsiorskiy et al. (1985) 120 None
CIRCUMFERENCE, LOWER LEG (DEC)
<14d > Zatsiorskiy et al. (1985) 120 None
CIRCUMFERENCE CALF (DEC)
>11d > Cherepakhin (1968) 62 None
>11d > Cherepakhin (1968) 62 Exercise
SKIN FOLD, LOWER LEG (INC)
<14d > Zatsiorskiy et al. (1985) 120 None
SKIN FOLD, THIGH (INC)
<14d > Zatsiorskiy et al. (1985) 120 None
SKIN FOLD, UPPER ARM (DEC)
>14d > Zatsiorskiy et al. (1985) 120 None
SKIN FOLD, UPPER TRUNK (INC)
<14d > Zatsiorskiy et al. (1985) 120 None
SKIN FOLD, MIDDLE TRUNK (INC)
<14d > Zatsiorskiy et al. (1985) 120 None
SKIN FOLD, LOWER TRUNK (INC)
<14d > Zatsiorskiy et al. (1985) 120 None
MUSCLE TONE (TIBIALIS ANTERIOR) (DEC)
>11d > Cherepakhin (1968) 62 None
<11d > Cherepakhin (1968) 62 Exercise
MUSCLE TONE (QUADRICEPS FEMORIS) (DEC)
>11d > Cherepakhin (1968) 62 None
>11d > Cherepakhin (1968) 62 Exercise
MUSCLE TONE (BICEPS BRACHII) (DEC)
<11d > Cherepakhin (1968) 62 None
<11d > Cherepakhin (1968) 62 Exercise
MUSCLE SYMPATHETIC NERVE ACTIVITY (BURST RATE) (NC)
>30d > Kamiya et al. (2000) 120 None
SOLEUS MUSCLE FIBERS: CROSS-SECTIONAL AREA (DEC)
<30d > Ohira et al. (1999) 120 None

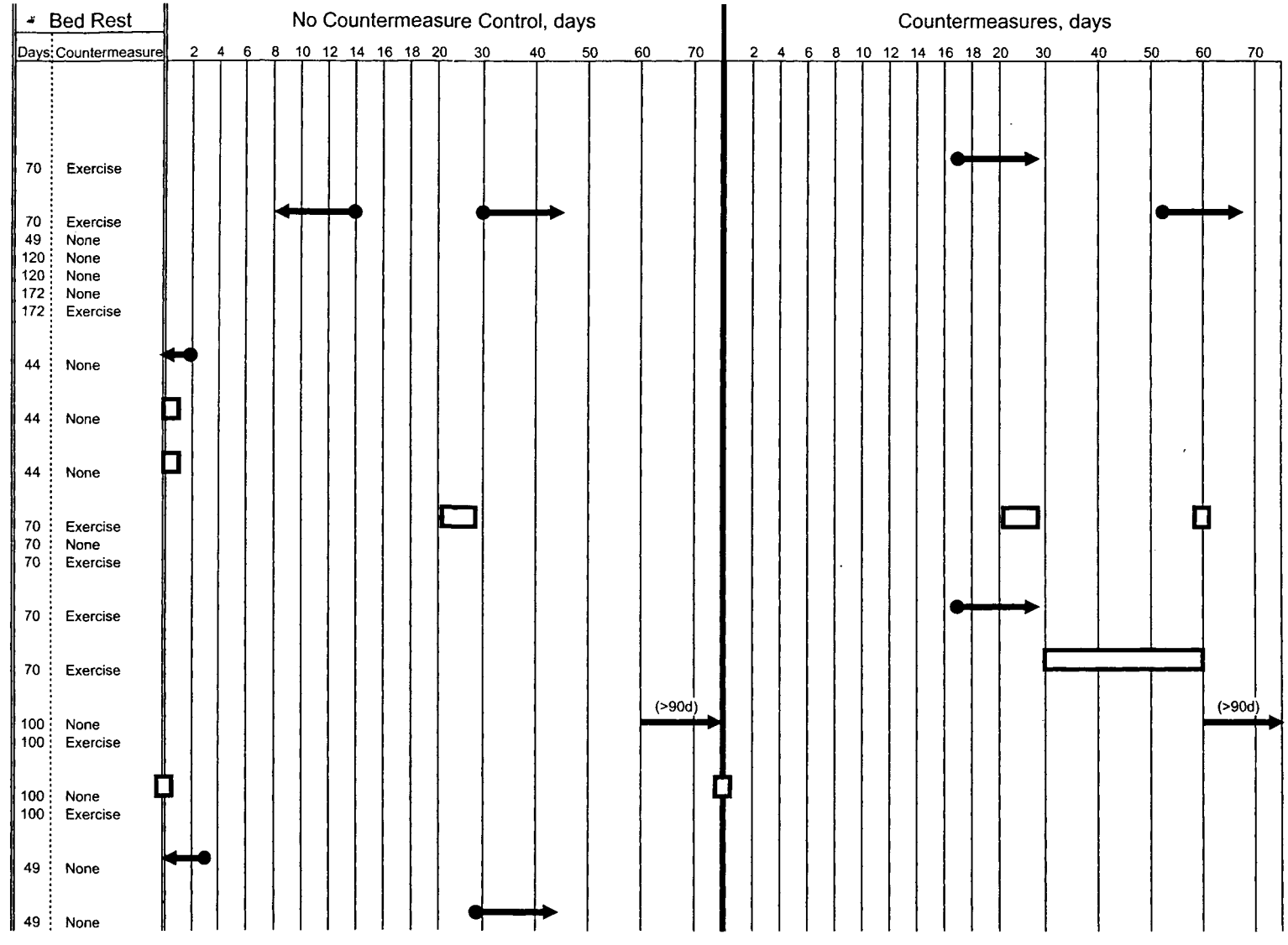

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
SOLEUS MUSCLE FIBERS: NO. MYONUCLEI (UNC)
0d > Ohira et al. (1999)
120 None
SOLEUS MUSCLE FIBERS: CYTOPLASMIC VOLUME (DEC)
<30d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES (I, I+IIa, I+IIa+IIx, IIa, IIa+IIx) (UNC)
0d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES CROSS-SECTIONAL AREA (I) (DEC)
<30d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES CROSS-SECTIONAL AREA (I+IIa) (UNC)
0d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES CROSS-SECTIONAL AREA (IIa) (UNC)
0d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES NO. MYONUCLEI (I, I+IIa, IIa) (UNC)
0d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES CYTOPLASMIC VOLUME (I) (DEC)
<30d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES CYTOPLASMIC VOLUME (I+IIa) (DEC)
<30d > Ohira et al. (1999)
120 None
SOLEUS FIBER TYPES CYTOPLASMIC VOLUME (IIa) (DEC)
>30d > Ohira et al. (1999)
120 None
INTERVERTEBRAL DISC CROSS-SECTIONAL AREA (INC)
>50d > Leblanc et al. (1994)
119 None
INTERVERTEBRAL DISC SIZE (INC)
>42d > Le Blanc et al. (1994)
119 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
BONE MINERAL (DEC)
~70d > Hulley et al. (1971)
>30d > Krasnykh (1969b)
210 None
70 Exercise
BONE MINERAL (TOTAL BODY) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (HEAD) (INC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (ARMS) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (PROXIMAL RADIUS) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (DISTAL RADIUS) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (PROXIMAL ULNA) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (DISTAL ULNA) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (RIBS) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (THORACIC SPINE) (UNC)
0d > Leblanc et al. (1990)
119 None
BONE MINERAL (LUMBAR SPINE) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (TOTAL SPINE) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (TRUNK) (DEC)
>180d > Leblanc et al. (1990)
119 None
(>180d)
BONE MINERAL (PELVIS) (DEC)
>180d > Leblanc et al. (1990)
119 None
(>180d)
BONE MINERAL (FEMORAL NECK) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (TROCHANTER) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)

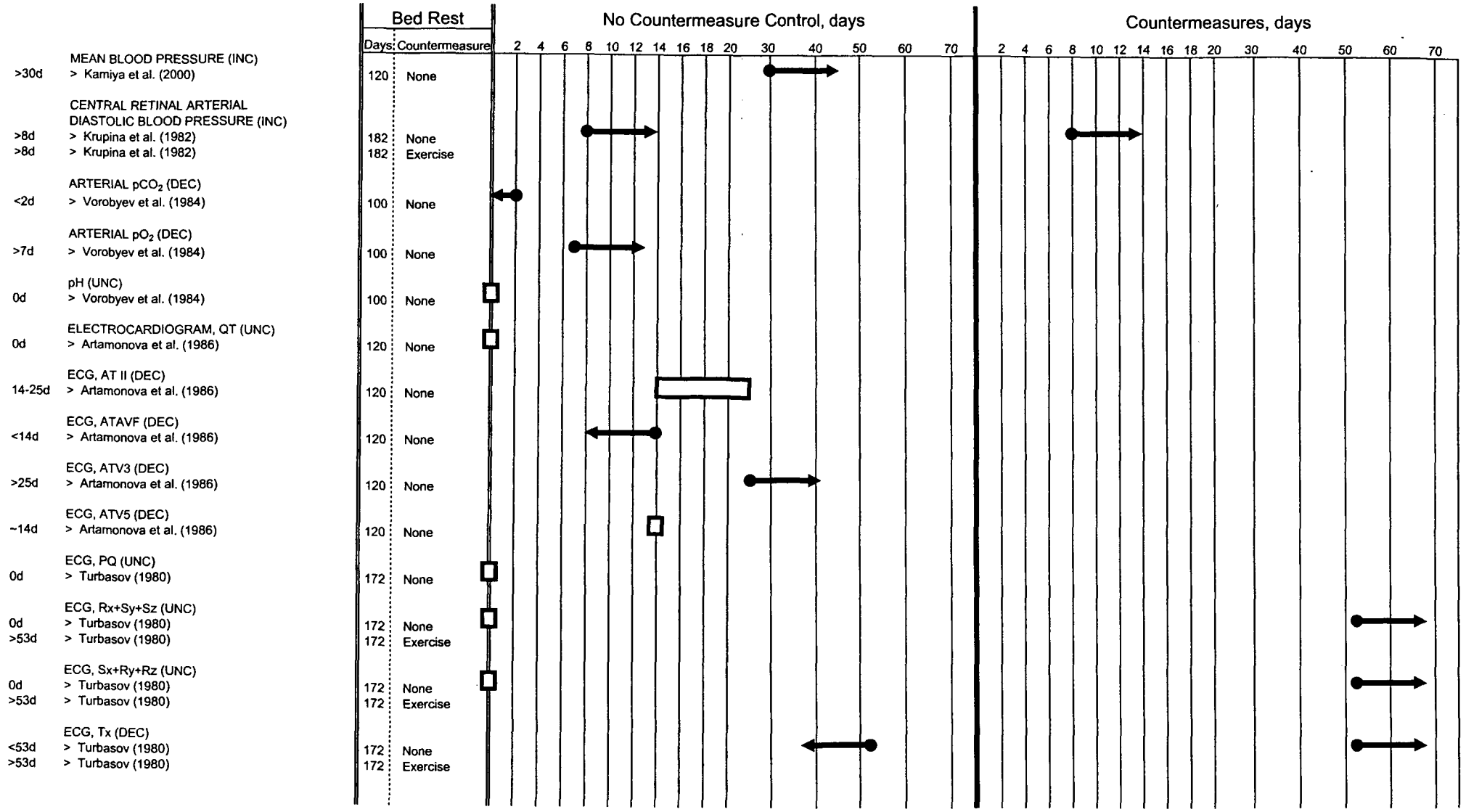

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
BONE MINERAL (TIBIA) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (TIBIA + FIBULA) (DEC)
<30d > Grigoriev et al. (1985)
120 None
>30d > Grigoriev et al. (1985)
120 Exercise
BONE MINERAL (LEGS) (DEC)
<180d > Leblanc et al. (1990)
119 None
(<180d)
BONE MINERAL (CALCANEUS) (DEC)
>180d > Leblanc et al. (1990)
119 None
(>180d)
BONE (TIBIA) ULTRASONIC MEAN VELOCITY (DEC)
>30d > Grigoriev et al. (1985)
120 None
0d > Grigoriev et al. (1985)
120 Exercise
BONE (TIBIA) ULTRASONIC LOWEST VELOCITY (DEC)
>30d > Grigoriev et al. (1985)
120 None
>30d > Grigoriev et al. (1985)
120 Exercise
BONE (TIBIA) ULTRASONIC (MAX-MIN VELOCITY) (DEC)
>30d > Grigoriev et al. (1985)
120 None
>30d > Grigoriev et al. (1985)
120 Exercise

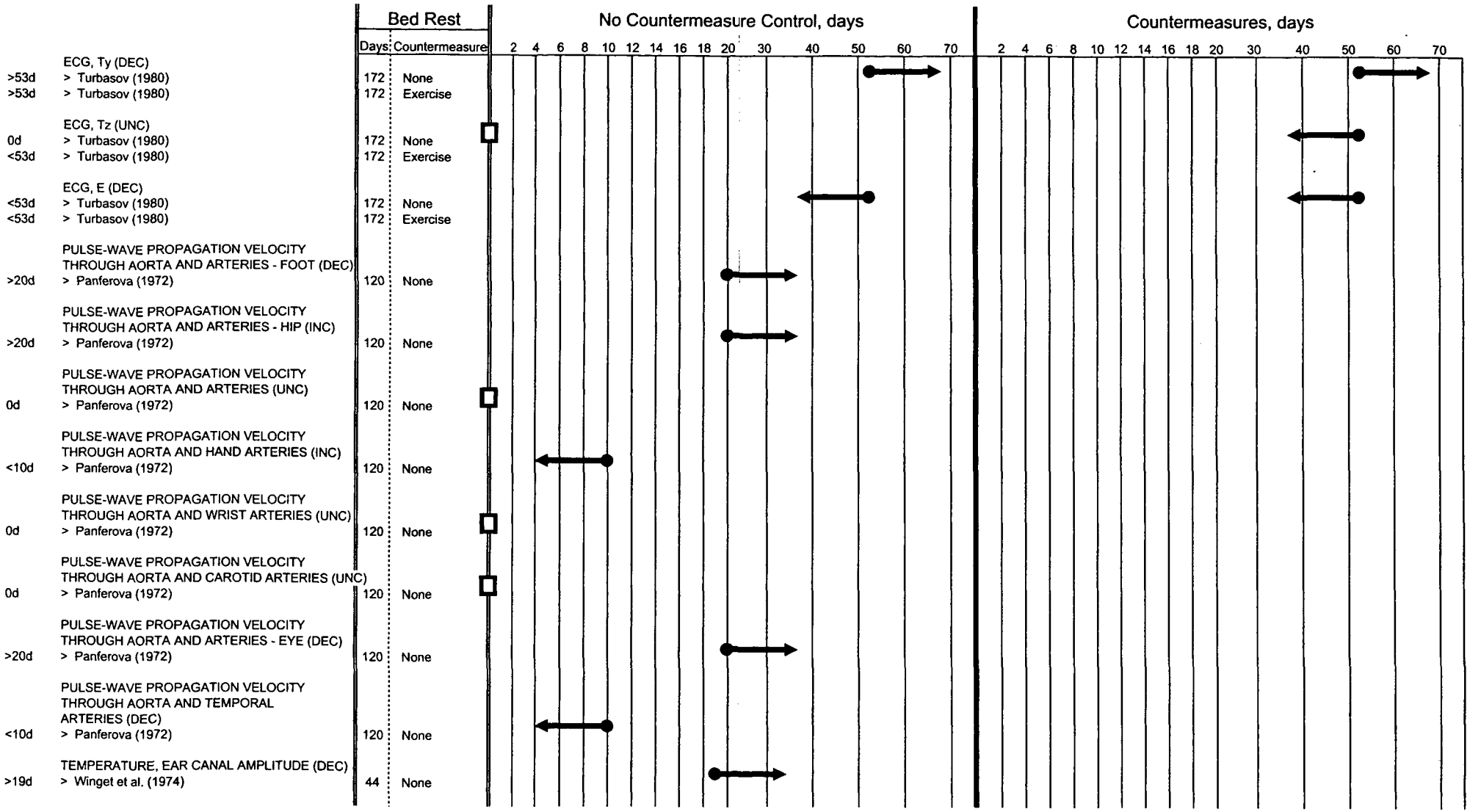
2. PHYSIOLOGICAL SYSTEMS

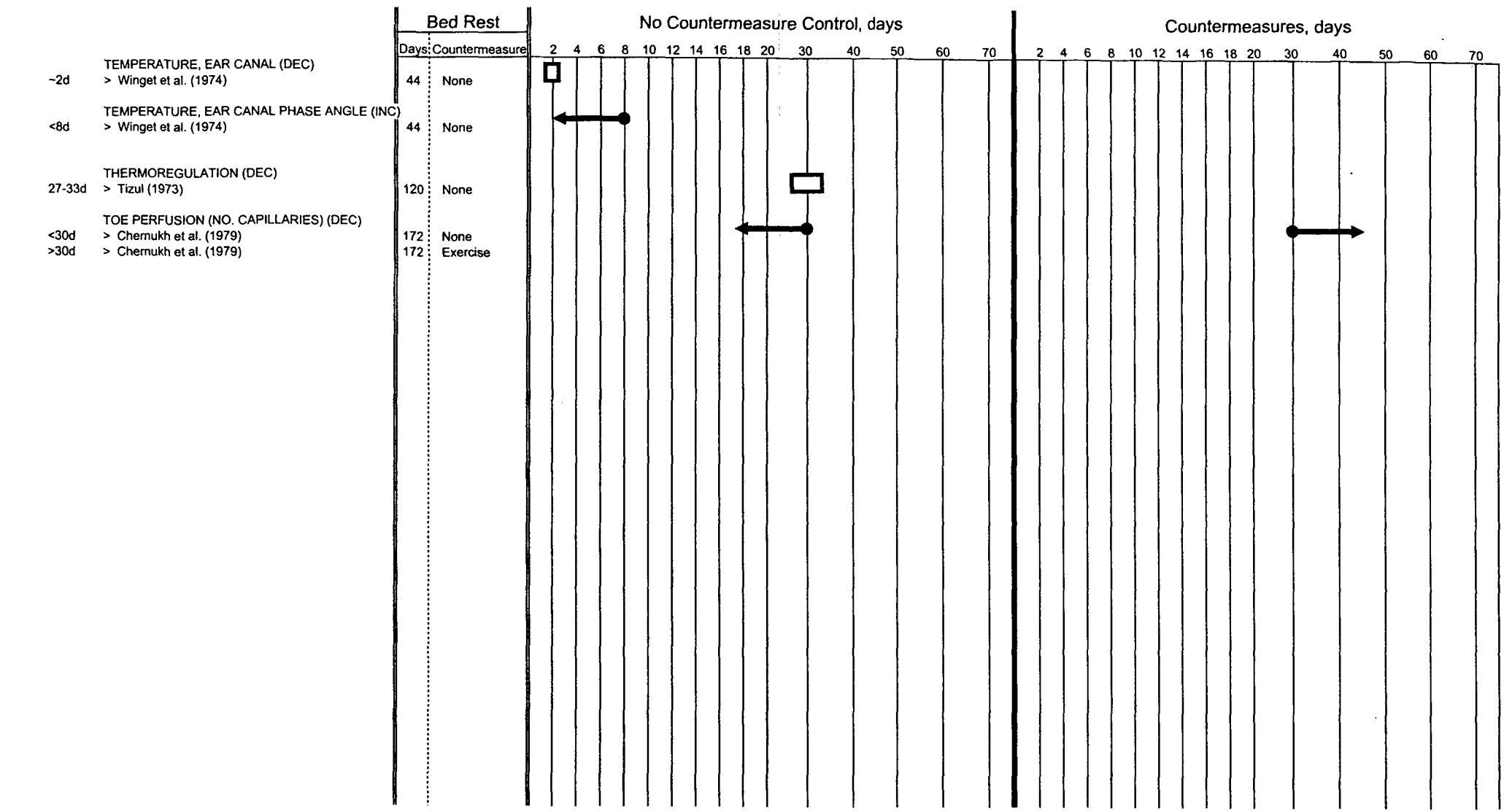
2A. Cardiovascular Variables



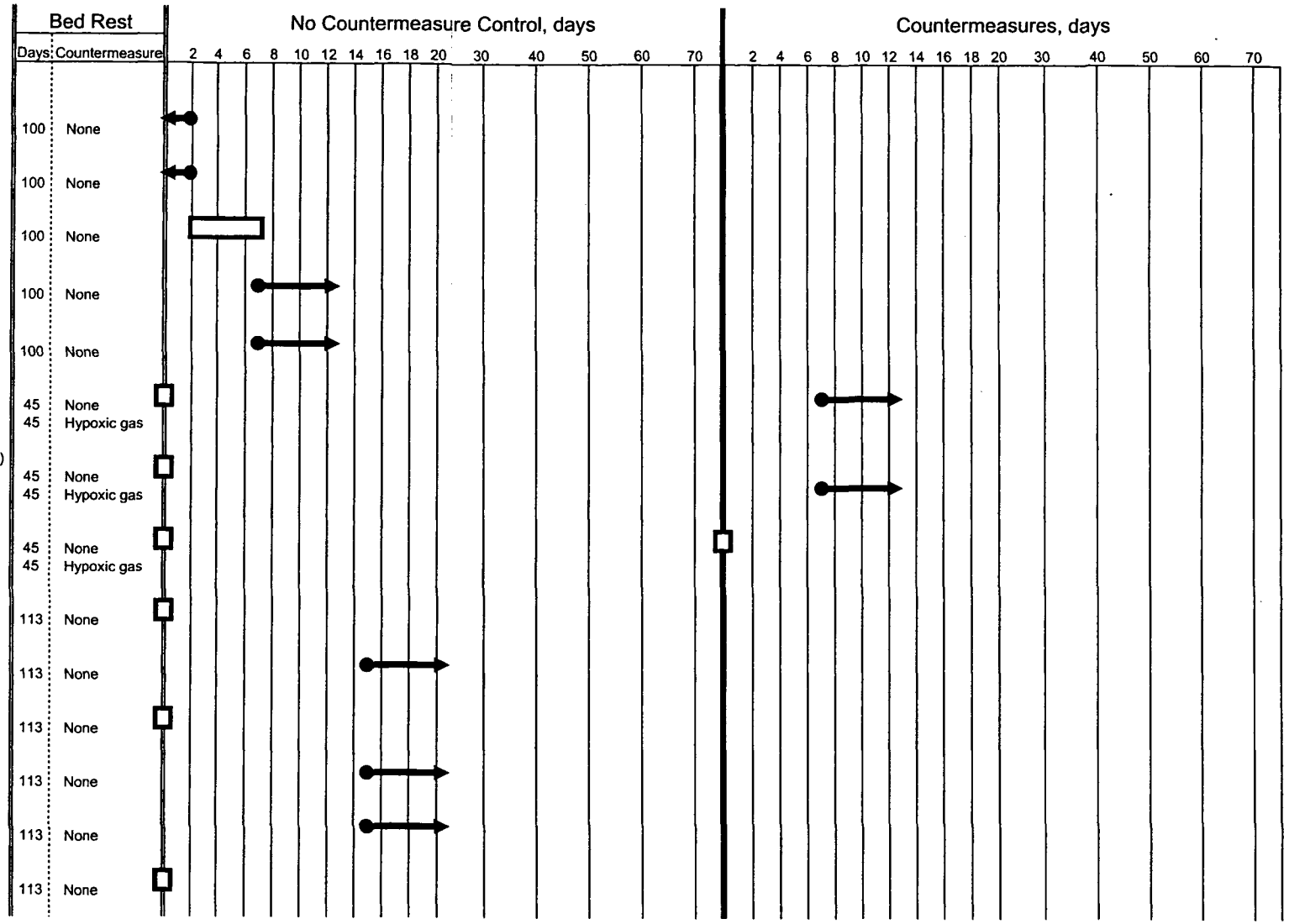
	HEART RATE, with tilting (INC)		
>17d	> Beregovkin et al. (1969)	70	Exercise
	HEART RATE, RESTING (INC)		
~125d	> Beregovkin et al. (1969)	70	Exercise
>42d	> Deitrick et al. (1948)	49	None
>30d	> Kamiya et al. (2000)	120	None
<14d	> Artamonova et al. (1986)	120	None
>53d	> Turbasov (1980)	172	None
>53d	> Turbasov (1980)	172	Exercise
	HEART RATE PHASE ANGLE (INC)		
<2d	> Winget et al. (1974)	44	None
	HEART RATE INTEGRATED AMPLITUDE (DEC)		
<1d	> Winget et al. (1974)	44	None
	HEART RATE DAILY MEANS (DEC)		
<1d	> Winget et al. (1974)	44	None
	HEART VENTRICULAR FUNCTION (DEC)		
~60d	> Beregovkin et al. (1969)	70	Exercise
21-28d	> Tishchenko et al. (1969)	70	None
21-28d	> Tishchenko et al. (1969)	70	Exercise
	HEART STROKE VOLUME (DEC)		
>17d	> Beregovkin et al. (1969)	70	Exercise
	HEART SIZE (DEC)		
30-60d	> Krasnykh et al. (1969a)	70	Exercise
	HEART VOLUME (SYSTOLIC) (DEC)		
>90d	> Krasnykh (1979a)	100	None
>90d	> Krasnykh (1979a)	100	Exercise
	HEART VOLUME (DIASTOLIC) (UNC)		
0d	> Krasnykh (1979a)	100	None
0d	> Krasnykh (1979a)	100	Exercise
	SYSTOLIC BLOOD PRESSURE (DEC)		
<3d	> Krupina et al. (1977)	49	None
	DIASTOLIC BLOOD PRESSURE (INC)		
>29d	> Krupina et al. (1977)	49	None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
MEAN BLOOD PRESSURE (INC)
>30d > Kamiya et al. (2000) 120 None
CENTRAL RETINAL ARTERIAL DIASTOLIC BLOOD PRESSURE (INC)
>8d > Krupina et al. (1982) 182 None
>8d > Krupina et al. (1982) 182 Exercise
ARTERIAL pCO2 (DEC)
<2d > Vorobyev et al. (1984) 100 None
ARTERIAL pO2 (DEC)
>7d > Vorobyev et al. (1984) 100 None
pH (UNC)
0d > Vorobyev et al. (1984) 100 None
ELECTROCARDIOGRAM, QT (UNC)
0d > Artamonova et al. (1986) 120 None
ECG, AT II (DEC)
14-25d > Artamonova et al. (1986) 120 None
ECG, ATAVF (DEC)
<14d > Artamonova et al. (1986) 120 None
ECG, ATV3 (DEC)
>25d > Artamonova et al. (1986) 120 None
ECG, ATV5 (DEC)
~14d > Artamonova et al. (1986) 120 None
ECG, PQ (UNC)
0d > Turbasov (1980) 172 None
ECG, Rx+Sy+Sz (UNC)
0d > Turbasov (1980) 172 None
>53d > Turbasov (1980) 172 Exercise
ECG, Sx+Ry+Rz (UNC)
0d > Turbasov (1980) 172 None
>53d > Turbasov (1980) 172 Exercise
ECG, Tx (DEC)
<53d > Turbasov (1980) 172 None
>53d > Turbasov (1980) 172 Exercise


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
ECG, Ty (DEC)
>53d > Turbasov (1980) 172 None
>53d > Turbasov (1980) 172 Exercise
ECG, Tz (UNC)
0d > Turbasov (1980) 172 None
<53d > Turbasov (1980) 172 Exercise
ECG, E (DEC)
<53d > Turbasov (1980) 172 None
<53d > Turbasov (1980) 172 Exercise
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND ARTERIES - FOOT (DEC)
>20d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND ARTERIES - HIP (INC)
>20d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND ARTERIES (UNC)
0d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND HAND ARTERIES (INC)
<10d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND WRIST ARTERIES (UNC)
0d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND CAROTID ARTERIES (UNC)
0d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND ARTERIES - EYE (DEC)
>20d > Panferova (1972) 120 None
PULSE-WAVE PROPAGATION VELOCITY THROUGH AORTA AND TEMPORAL ARTERIES (DEC)
<10d > Panferova (1972) 120 None
TEMPERATURE, EAR CANAL AMPLITUDE (DEC)
>19d > Winget et al. (1974) 44 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days: Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
TEMPERATURE, EAR CANAL (DEC)
~2d > Winget et al. (1974) 44 None
TEMPERATURE, EAR CANAL PHASE ANGLE (INC)
<8d > Winget et al. (1974) 44 None
THERMOREGULATION (DEC)
27-33d > Tizul (1973) 120 None
TOE PERFUSION (NO. CAPILLARIES) (DEC)
<30d > Chernukh et al. (1979) 172 None
>30d > Chernukh et al. (1979) 172 Exercise

2B. Respiratory Variables



RESPIRATORY MINUTE VOLUME (DEC)
<2d > Vorobyev et al. (1984) 100 None

RESPIRATORY RATE (DEC)
<2d > Vorobyev et al. (1984) 100 None

RESPIRATORY RESISTANCE (INC)
2-7d > Vorobyev et al. (1984) 100 None

ALVEOLAR pO_2 (INC)
>7d > Vorobyev et al. (1984) 100 None

ALVEOLAR - ARTERIAL O_2 GRADIENT (INC)
>7d > Vorobyev et al. (1984) 100 None

LUNG DIFFUSION CAPACITY (UNC)
0d > Kotov (1977) 45 None
>7d > Kotov (1977) 45 Hypoxic gas

LUNG DIFFUSION MEMBRANE CAPACITY (UNC)
0d > Kotov (1977) 45 None
>7d > Kotov (1977) 45 Hypoxic gas

LUNG DIFFUSION CAPILLARY CAPACITY (UNC)
0d > Kotov (1977) 45 None
0d > Kotov (1977) 45 Hypoxic gas

PEAK EXPIRATORY FLOW (UNC)
0d > Montmerle et al. (2002) 113 None

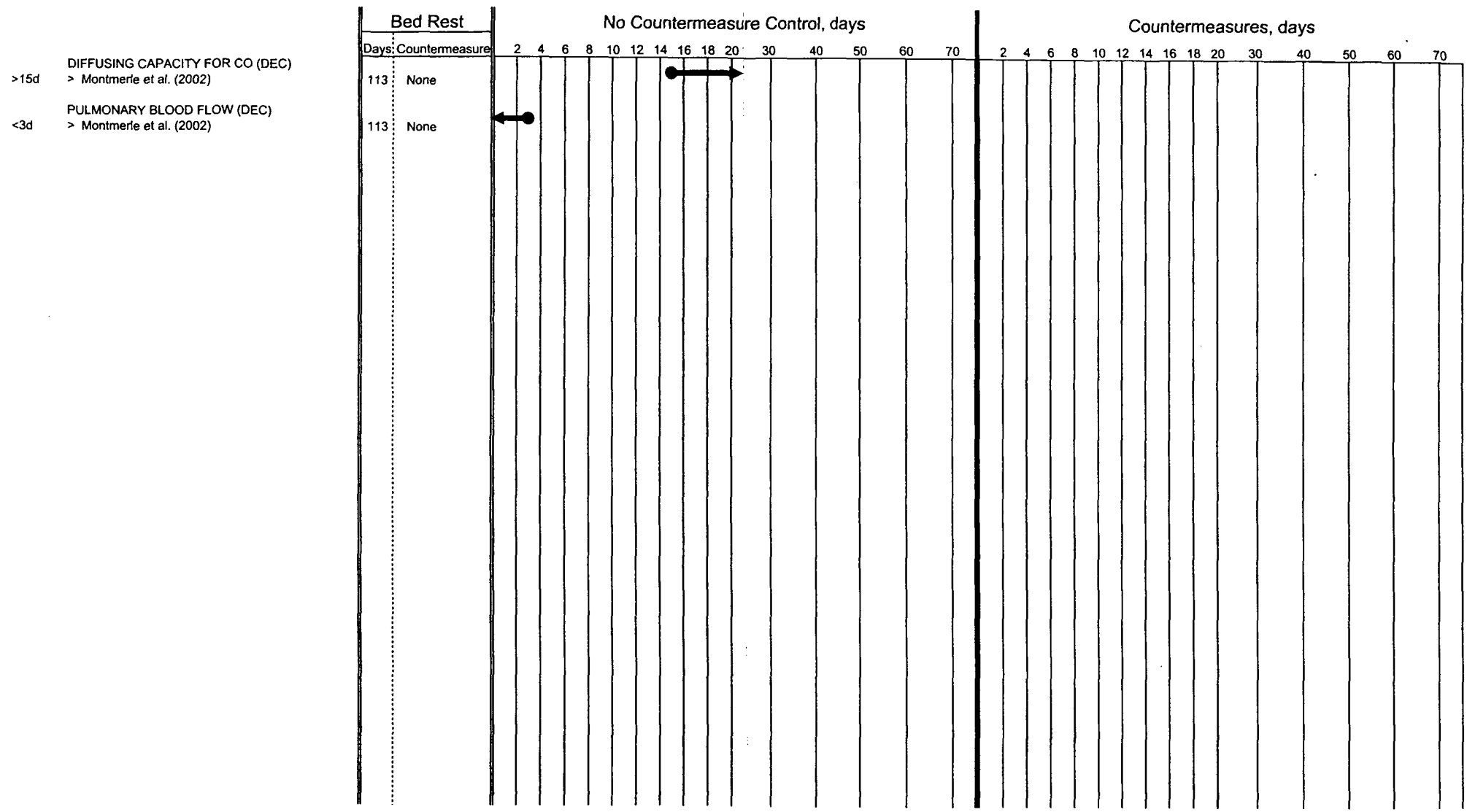
FORCED EXPIRATORY VOLUME (DEC)
>15d > Montmerle et al. (2002) 113 None

MAXIMAL MIDEXPIRATORY FLOW RATE (UNC)
0d > Montmerle et al. (2002) 113 None

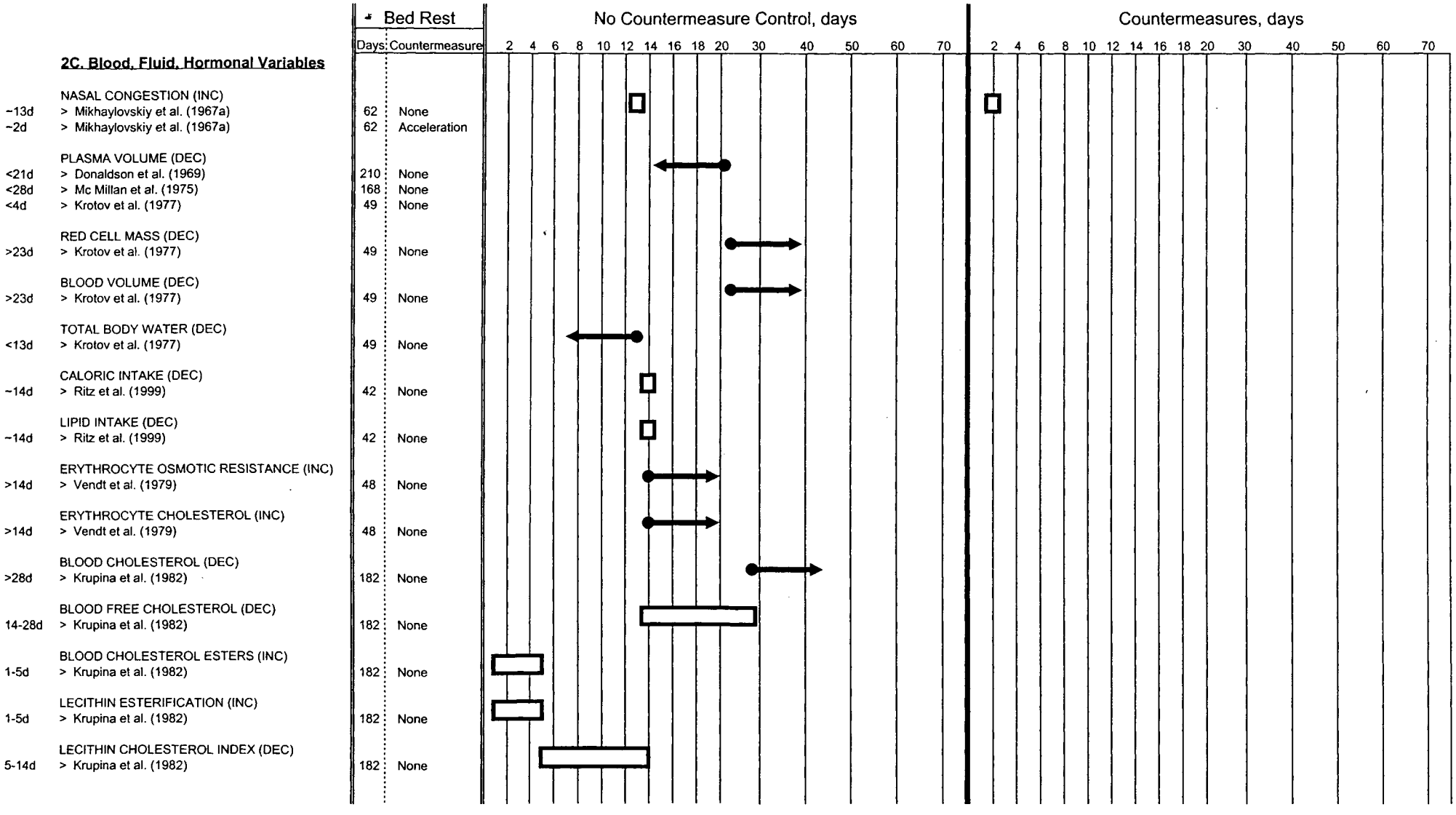
FORCED VITAL CAPACITY (DEC)
>15d > Montmerle et al. (2002) 113 None

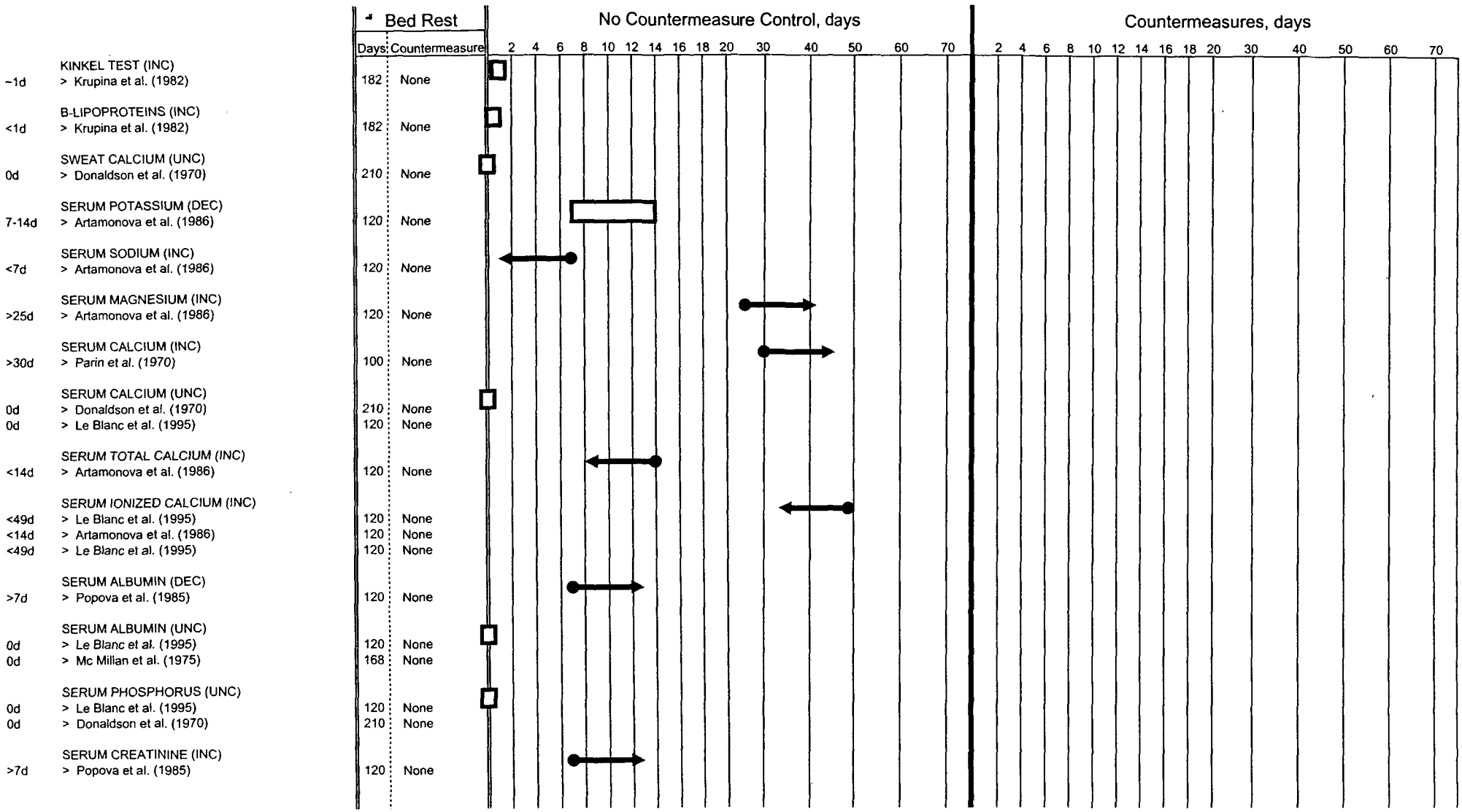
VITAL CAPACITY (DEC)
>15d > Montmerle et al. (2002) 113 None

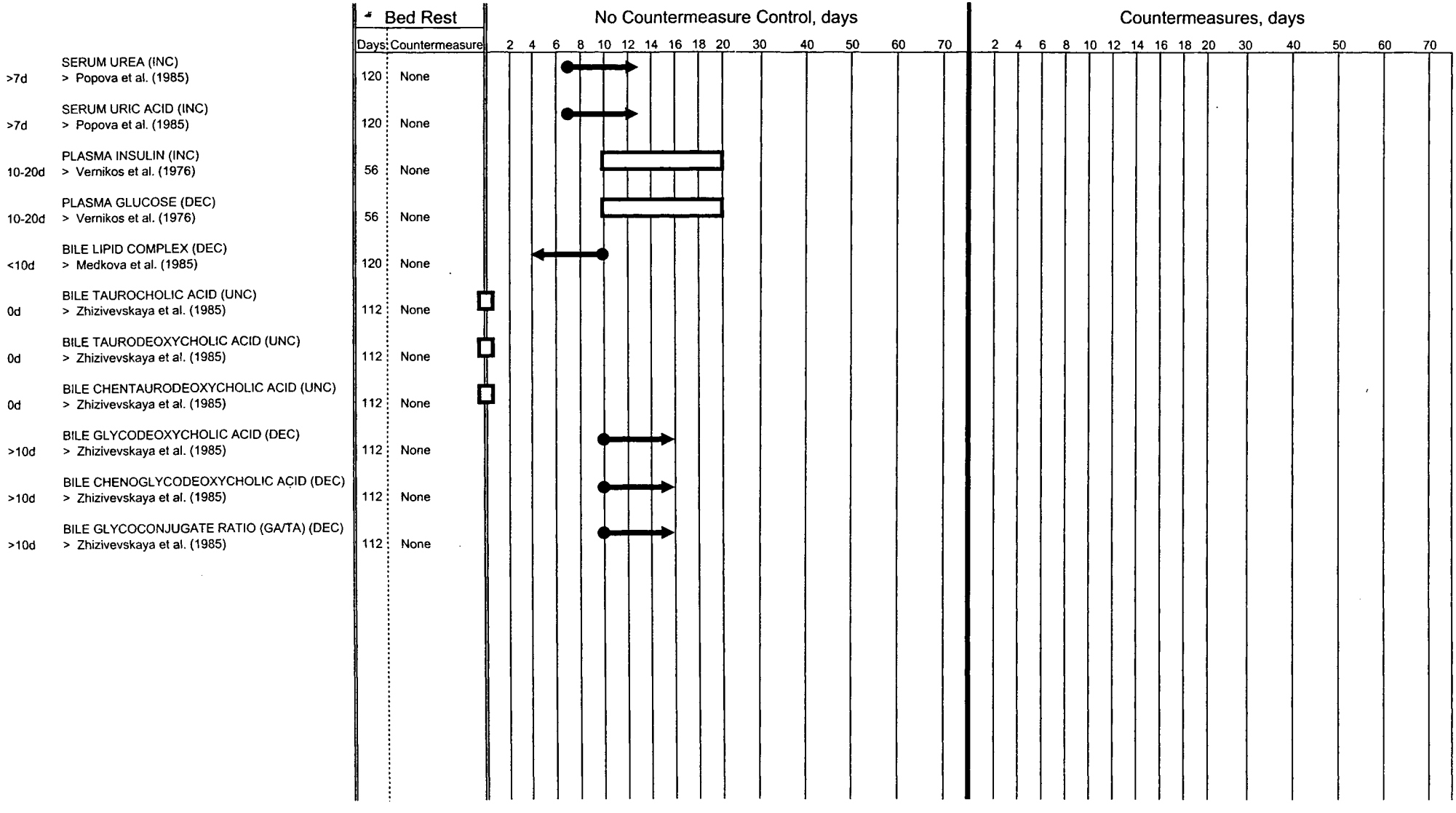
FUNCTIONAL RESIDUAL CAPACITY (UNC)
0d > Montmerle et al. (2002) 113 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days: Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
DIFFUSING CAPACITY FOR CO (DEC)
>15d > Montmerle et al. (2002)
113 None
PULMONARY BLOOD FLOW (DEC)
<3d > Montmerle et al. (2002)
113 None

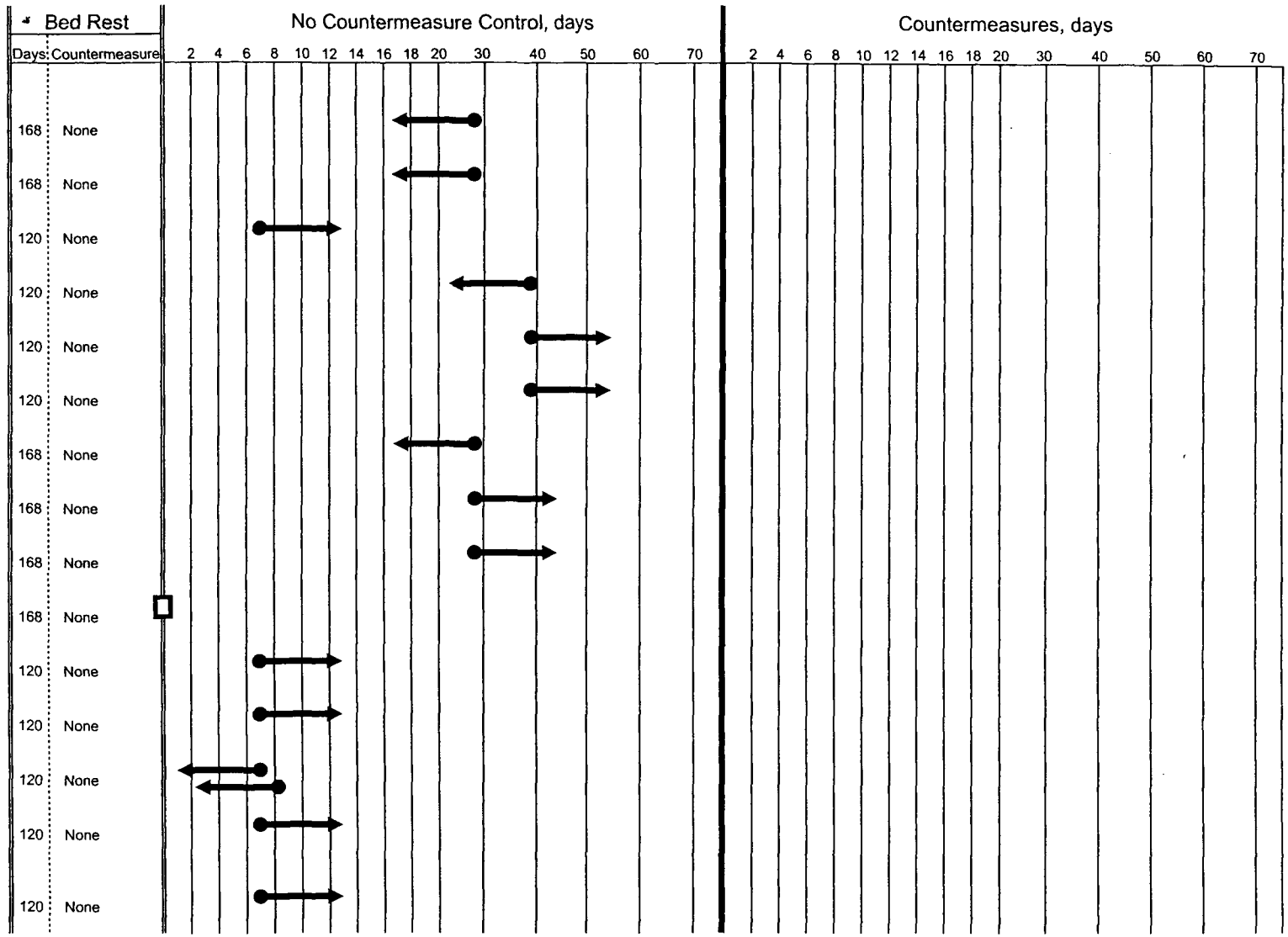
2C. Blood, Fluid, Hormonal Variables

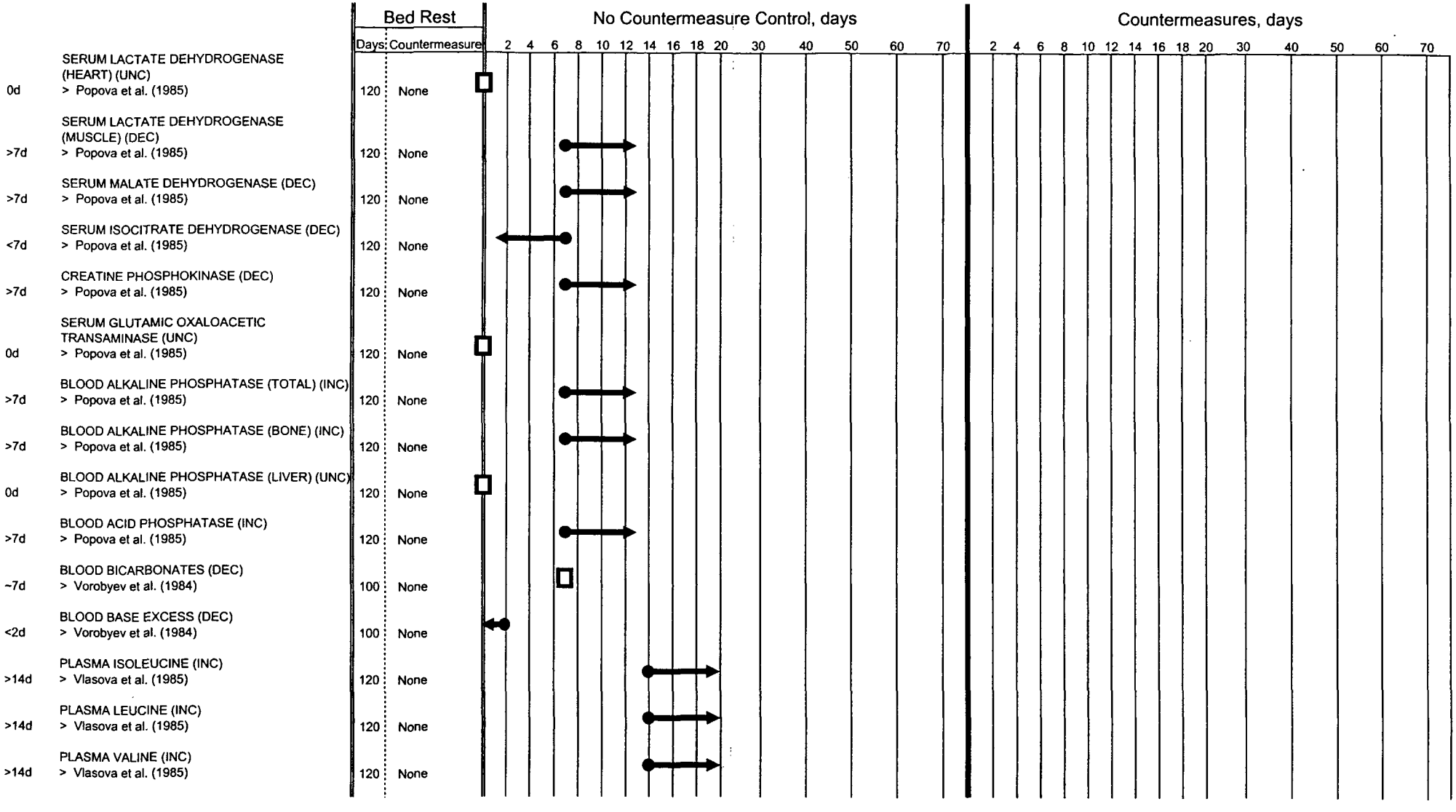


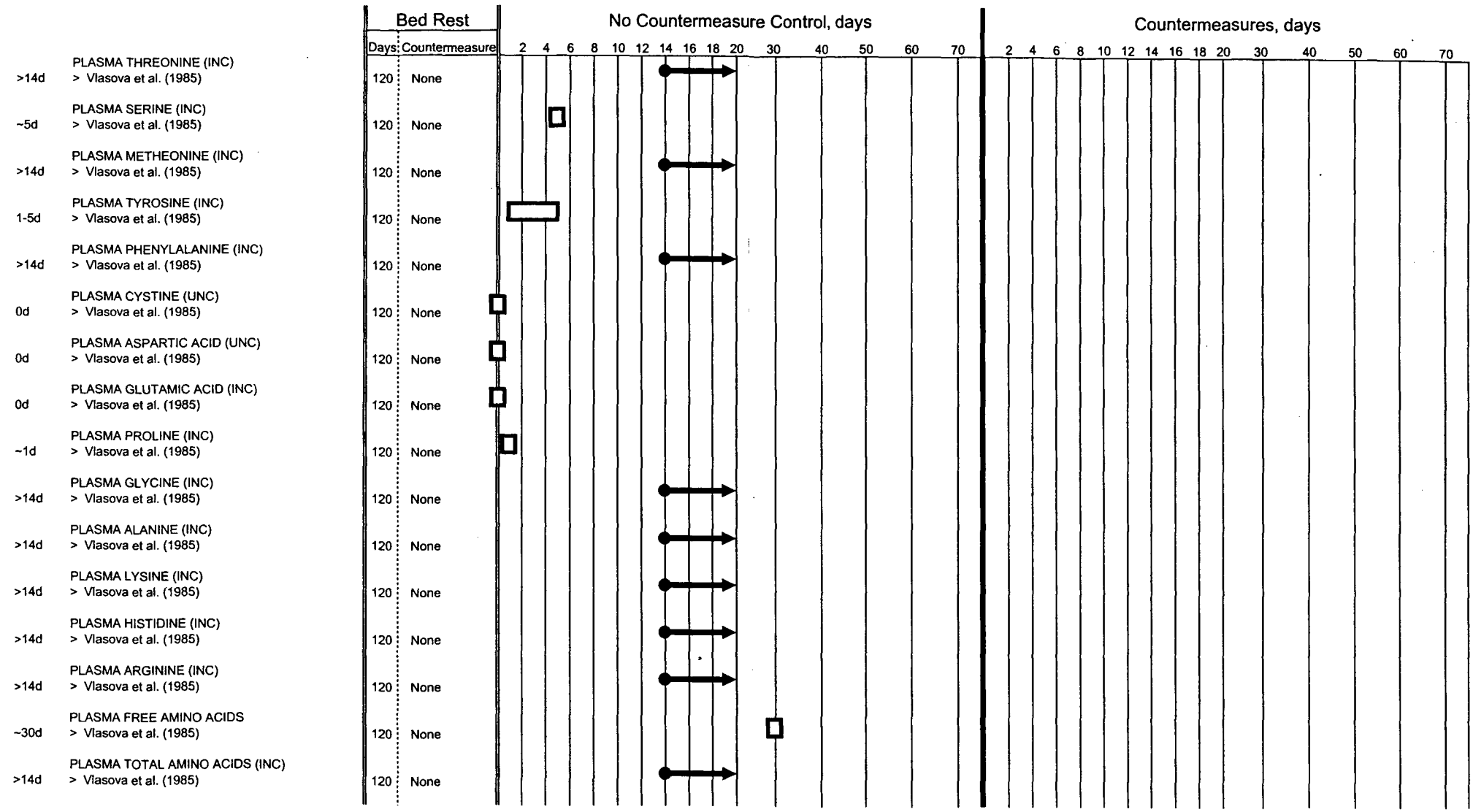

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
KINKEL TEST (INC)
~1d > Krupina et al. (1982) 182 None
B-LIPOPROTEINS (INC)
<1d > Krupina et al. (1982) 182 None
SWEAT CALCIUM (UNC)
0d > Donaldson et al. (1970) 210 None
SERUM POTASSIUM (DEC)
7-14d > Artamonova et al. (1986) 120 None
SERUM SODIUM (INC)
<7d > Artamonova et al. (1986) 120 None
SERUM MAGNESIUM (INC)
>25d > Artamonova et al. (1986) 120 None
SERUM CALCIUM (INC)
>30d > Parin et al. (1970) 100 None
SERUM CALCIUM (UNC)
0d > Donaldson et al. (1970) 210 None
0d > Le Blanc et al. (1995) 120 None
SERUM TOTAL CALCIUM (INC)
<14d > Artamonova et al. (1986) 120 None
SERUM IONIZED CALCIUM (INC)
<49d > Le Blanc et al. (1995) 120 None
<14d > Artamonova et al. (1986) 120 None
<49d > Le Blanc et al. (1995) 120 None
SERUM ALBUMIN (DEC)
>7d > Popova et al. (1985) 120 None
SERUM ALBUMIN (UNC)
0d > Le Blanc et al. (1995) 120 None
0d > Mc Millan et al. (1975) 168 None
SERUM PHOSPHORUS (UNC)
0d > Le Blanc et al. (1995) 120 None
0d > Donaldson et al. (1970) 210 None
SERUM CREATININE (INC)
>7d > Popova et al. (1985) 120 None

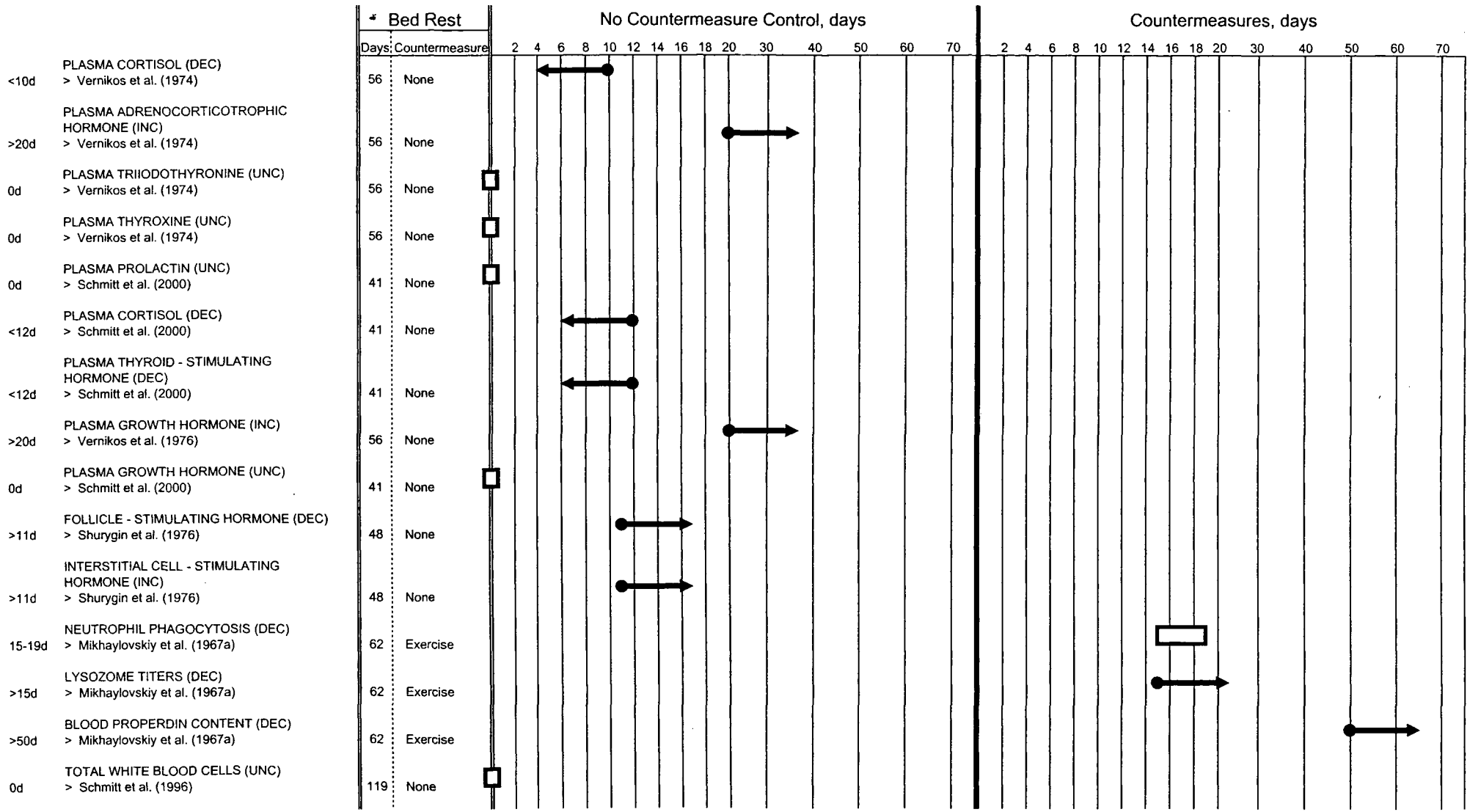

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
SERUM UREA (INC)
>7d > Popova et al. (1985) 120 None
SERUM URIC ACID (INC)
>7d > Popova et al. (1985) 120 None
PLASMA INSULIN (INC)
10-20d > Vernikos et al. (1976) 56 None
PLASMA GLUCOSE (DEC)
10-20d > Vernikos et al. (1976) 56 None
BILE LIPID COMPLEX (DEC)
<10d > Medkova et al. (1985) 120 None
BILE TAUROCHOLIC ACID (UNC)
0d > Zhizivevskaya et al. (1985) 112 None
BILE TAURODEOXYCHOLIC ACID (UNC)
0d > Zhizivevskaya et al. (1985) 112 None
BILE CHENTAURODEOXYCHOLIC ACID (UNC)
0d > Zhizivevskaya et al. (1985) 112 None
BILE GLYCODEOXYCHOLIC ACID (DEC)
>10d > Zhizivevskaya et al. (1985) 112 None
BILE CHENOGLYCODEOXYCHOLIC ACID (DEC)
>10d > Zhizivevskaya et al. (1985) 112 None
BILE GLYCOCONJUGATE RATIO (GA/TA) (DEC)
>10d > Zhizivevskaya et al. (1985) 112 None

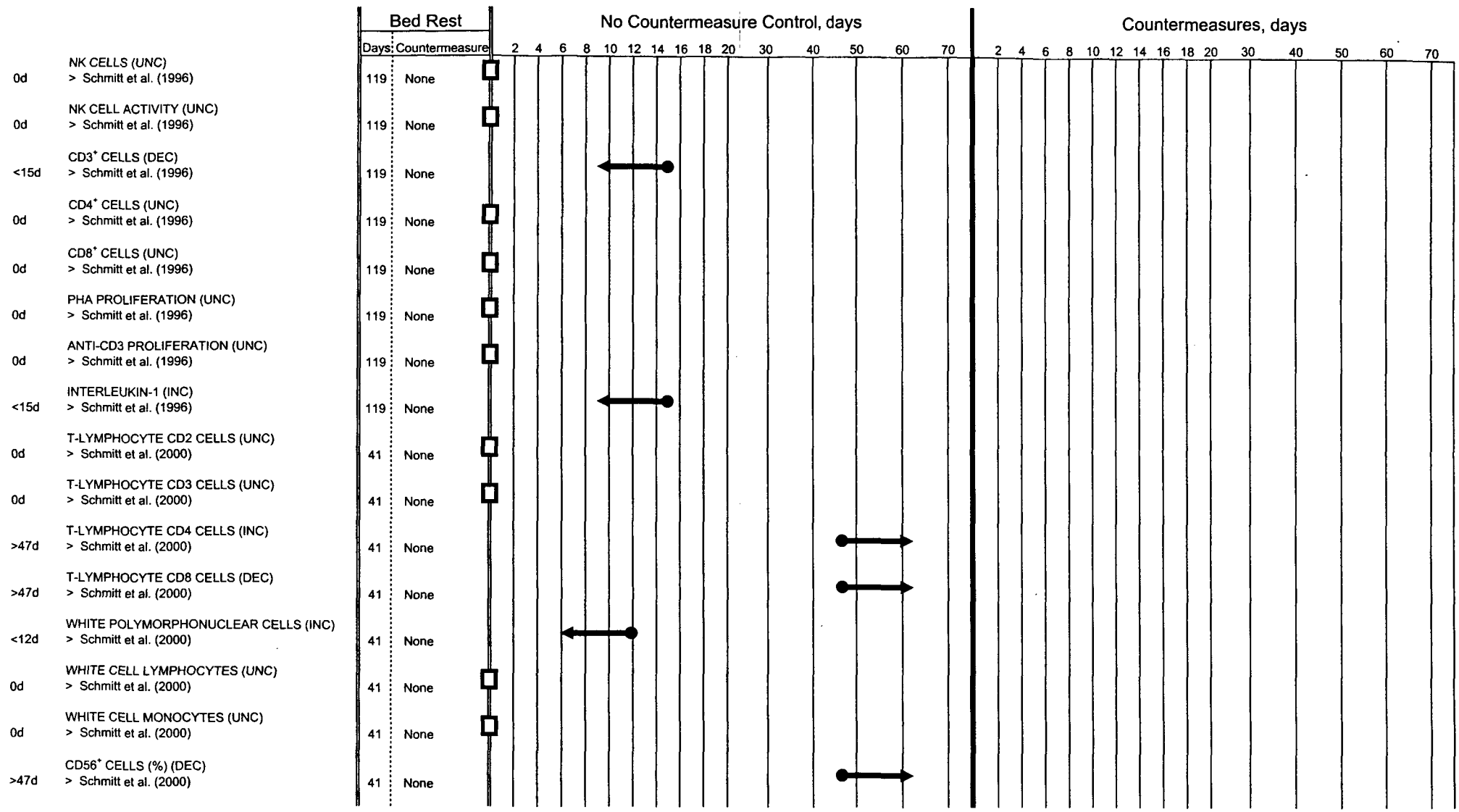
2D. Cellular, Enzyme Variables

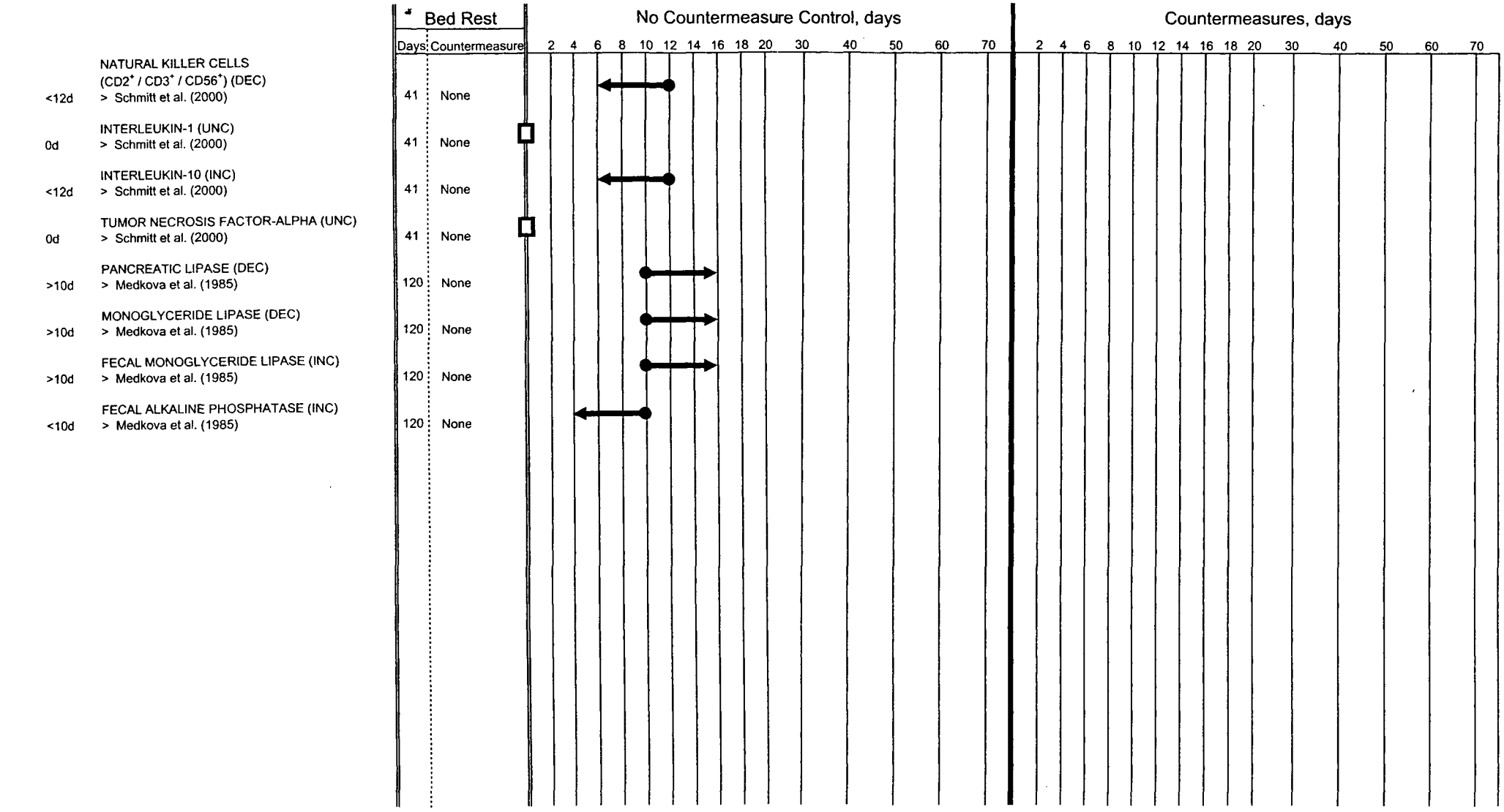



Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
SERUM LACTATE DEHYDROGENASE (HEART) (UNC)
0d > Popova et al. (1985) 120 None
SERUM LACTATE DEHYDROGENASE (MUSCLE) (DEC)
>7d > Popova et al. (1985) 120 None
SERUM MALATE DEHYDROGENASE (DEC)
>7d > Popova et al. (1985) 120 None
SERUM ISOCITRATE DEHYDROGENASE (DEC)
<7d > Popova et al. (1985) 120 None
CREATINE PHOSPHOKINASE (DEC)
>7d > Popova et al. (1985) 120 None
SERUM GLUTAMIC OXALOACETIC TRANSAMINASE (UNC)
0d > Popova et al. (1985) 120 None
BLOOD ALKALINE PHOSPHATASE (TOTAL) (INC)
>7d > Popova et al. (1985) 120 None
BLOOD ALKALINE PHOSPHATASE (BONE) (INC)
>7d > Popova et al. (1985) 120 None
BLOOD ALKALINE PHOSPHATASE (LIVER) (UNC)
0d > Popova et al. (1985) 120 None
BLOOD ACID PHOSPHATASE (INC)
>7d > Popova et al. (1985) 120 None
BLOOD BICARBONATES (DEC)
~7d > Vorobyev et al. (1984) 100 None
BLOOD BASE EXCESS (DEC)
<2d > Vorobyev et al. (1984) 100 None
PLASMA ISOLEUCINE (INC)
>14d > Vlasova et al. (1985) 120 None
PLASMA LEUCINE (INC)
>14d > Vlasova et al. (1985) 120 None
PLASMA VALINE (INC)
>14d > Vlasova et al. (1985) 120 None

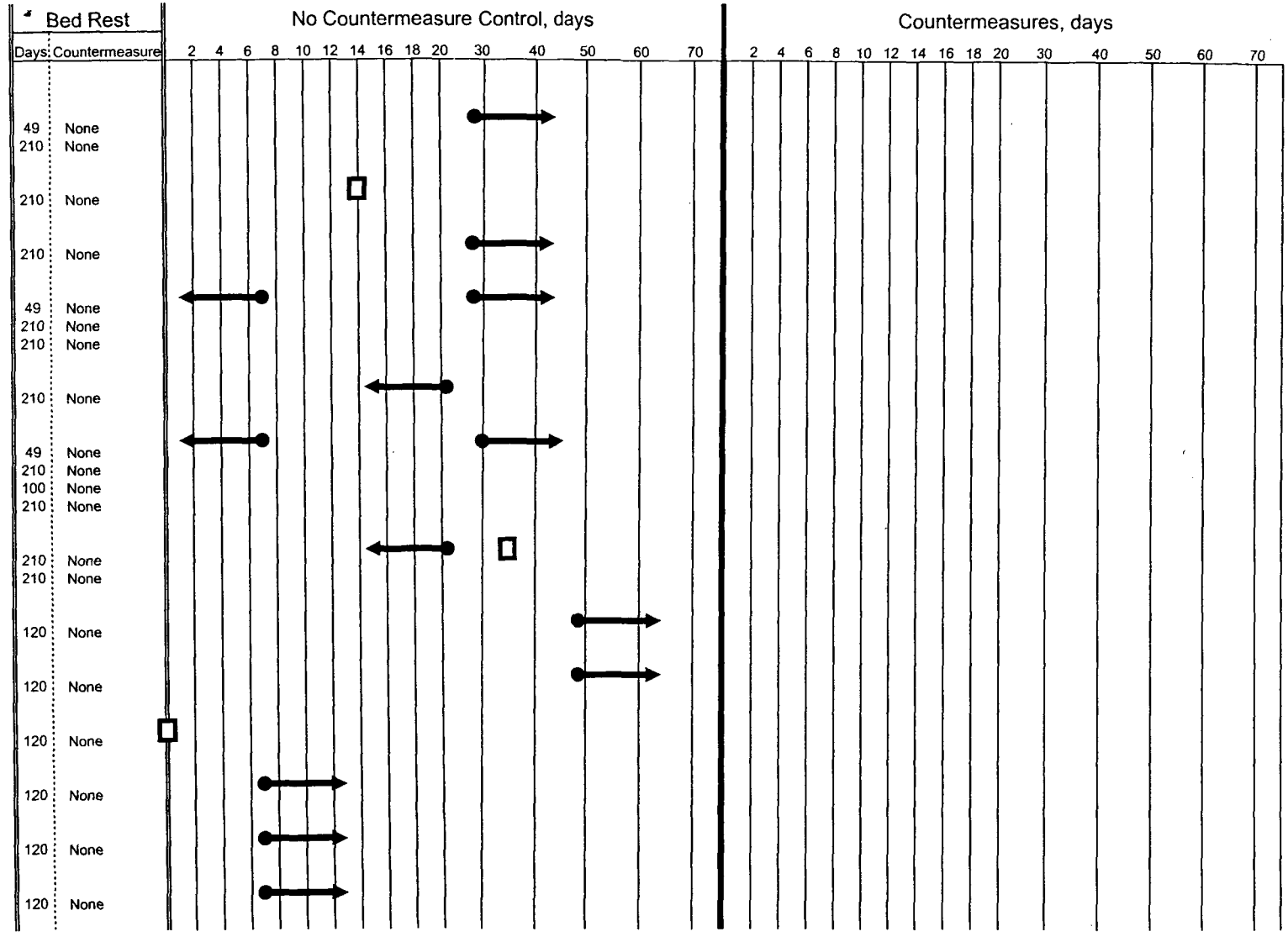

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
PLASMA THREONINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA SERINE (INC)
~5d > Vlasova et al. (1985)
120 None
PLASMA METHEONINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA TYROSINE (INC)
1-5d > Vlasova et al. (1985)
120 None
PLASMA PHENYLALANINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA CYSTINE (UNC)
0d > Vlasova et al. (1985)
120 None
PLASMA ASPARTIC ACID (UNC)
0d > Vlasova et al. (1985)
120 None
PLASMA GLUTAMIC ACID (INC)
0d > Vlasova et al. (1985)
120 None
PLASMA PROLINE (INC)
~1d > Vlasova et al. (1985)
120 None
PLASMA GLYCINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA ALANINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA LYSINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA HISTIDINE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA ARGININE (INC)
>14d > Vlasova et al. (1985)
120 None
PLASMA FREE AMINO ACIDS
~30d > Vlasova et al. (1985)
120 None
PLASMA TOTAL AMINO ACIDS (INC)
>14d > Vlasova et al. (1985)
120 None

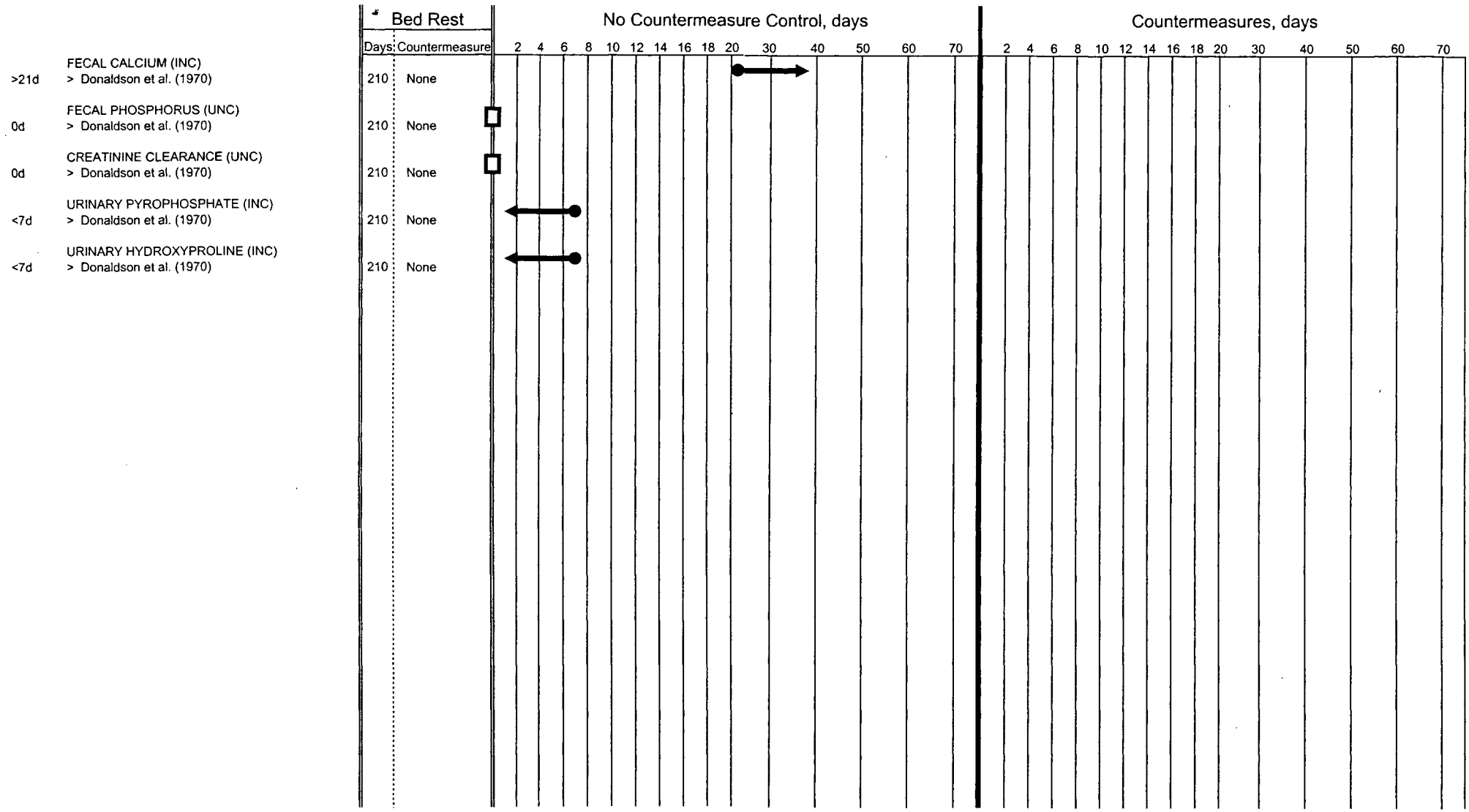

Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
<10d PLASMA CORTISOL (DEC) > Vernikos et al. (1974) 56 None
>20d PLASMA ADRENOCORTICOTROPHIC HORMONE (INC) > Vernikos et al. (1974) 56 None
0d PLASMA TRIIODOTHYRONINE (UNC) > Vernikos et al. (1974) 56 None
0d PLASMA THYROXINE (UNC) > Vernikos et al. (1974) 56 None
0d PLASMA PROLACTIN (UNC) > Schmitt et al. (2000) 41 None
<12d PLASMA CORTISOL (DEC) > Schmitt et al. (2000) 41 None
<12d PLASMA THYROID - STIMULATING HORMONE (DEC) > Schmitt et al. (2000) 41 None
>20d PLASMA GROWTH HORMONE (INC) > Vernikos et al. (1976) 56 None
0d PLASMA GROWTH HORMONE (UNC) > Schmitt et al. (2000) 41 None
>11d FOLLICLE - STIMULATING HORMONE (DEC) > Shurygin et al. (1976) 48 None
>11d INTERSTITIAL CELL - STIMULATING HORMONE (INC) > Shurygin et al. (1976) 48 None
15-19d NEUTROPHIL PHAGOCYTOSIS (DEC) > Mikhaylovskiy et al. (1967a) 62 Exercise
>15d LYSOZOME TITERS (DEC) > Mikhaylovskiy et al. (1967a) 62 Exercise
>50d BLOOD PROPERDIN CONTENT (DEC) > Mikhaylovskiy et al. (1967a) 62 Exercise
0d TOTAL WHITE BLOOD CELLS (UNC) > Schmitt et al. (1996) 119 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
NK CELLS (UNC)
0d > Schmitt et al. (1996) 119 None
NK CELL ACTIVITY (UNC)
0d > Schmitt et al. (1996) 119 None
CD3+ CELLS (DEC)
<15d > Schmitt et al. (1996) 119 None
CD4+ CELLS (UNC)
0d > Schmitt et al. (1996) 119 None
CD8+ CELLS (UNC)
0d > Schmitt et al. (1996) 119 None
PHA PROLIFERATION (UNC)
0d > Schmitt et al. (1996) 119 None
ANTI-CD3 PROLIFERATION (UNC)
0d > Schmitt et al. (1996) 119 None
INTERLEUKIN-1 (INC)
<15d > Schmitt et al. (1996) 119 None
T-LYMPHOCYTE CD2 CELLS (UNC)
0d > Schmitt et al. (2000) 41 None
T-LYMPHOCYTE CD3 CELLS (UNC)
0d > Schmitt et al. (2000) 41 None
T-LYMPHOCYTE CD4 CELLS (INC)
>47d > Schmitt et al. (2000) 41 None
T-LYMPHOCYTE CD8 CELLS (DEC)
>47d > Schmitt et al. (2000) 41 None
WHITE POLYMORPHONUCLEAR CELLS (INC)
<12d > Schmitt et al. (2000) 41 None
WHITE CELL LYMPHOCYTES (UNC)
0d > Schmitt et al. (2000) 41 None
WHITE CELL MONOCYTES (UNC)
0d > Schmitt et al. (2000) 41 None
CD56+ CELLS (%) (DEC)
>47d > Schmitt et al. (2000) 41 None


Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
NATURAL KILLER CELLS (CD2+ / CD3+ / CD56+) (DEC)
<12d > Schmitt et al. (2000)
41 None
INTERLEUKIN-1 (UNC)
0d > Schmitt et al. (2000)
41 None
INTERLEUKIN-10 (INC)
<12d > Schmitt et al. (2000)
41 None
TUMOR NECROSIS FACTOR-ALPHA (UNC)
0d > Schmitt et al. (2000)
41 None
PANCREATIC LIPASE (DEC)
>10d > Medkova et al. (1985)
120 None
MONOGLYCERIDE LIPASE (DEC)
>10d > Medkova et al. (1985)
120 None
FECAL MONOGLYCERIDE LIPASE (INC)
>10d > Medkova et al. (1985)
120 None
FECAL ALKALINE PHOSPHATASE (INC)
<10d > Medkova et al. (1985)
120 None

2E. Urinary-Renal Variables




Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
FECAL CALCIUM (INC)
>21d > Donaldson et al. (1970)
210 None
FECAL PHOSPHORUS (UNC)
0d > Donaldson et al. (1970)
210 None
CREATININE CLEARANCE (UNC)
0d > Donaldson et al. (1970)
210 None
URINARY PYROPHOSPHATE (INC)
<7d > Donaldson et al. (1970)
210 None
URINARY HYDROXYPROLINE (INC)
<7d > Donaldson et al. (1970)
210 None

3. PHYSIOLOGICAL TESTS

MAXIMAL OXYGEN UPTAKE (DEC)
- >2d > Kakurin et al. (1975)
- <2d > Kakurin et al. (1975)
- ~18d > Birkhead et al. (1963)

MAXIMAL ENDURANCE (DEC)
- >2d > Kakurin et al. (1975)
- <2d > Kakurin et al. (1975)

MAXIMAL HEART RATE (INC)
- ~18d > Birkhead et al. (1963)
- >2d > Kakurin et al. (1975)
- <2d > Kakurin et al. (1975)

SUBMAXIMAL HEART RATE (INC)
- ~15d > Beregovkin et al. (1969)
- 16-36d > Deitrick et al. (1948)
- ~30d > Kotovskaya et al. (1969)
- ~19d > Mikhaylovskiy et al. (1967b)

STEP TEST (DEC)
- ~42d > Deitrick et al. (1948)

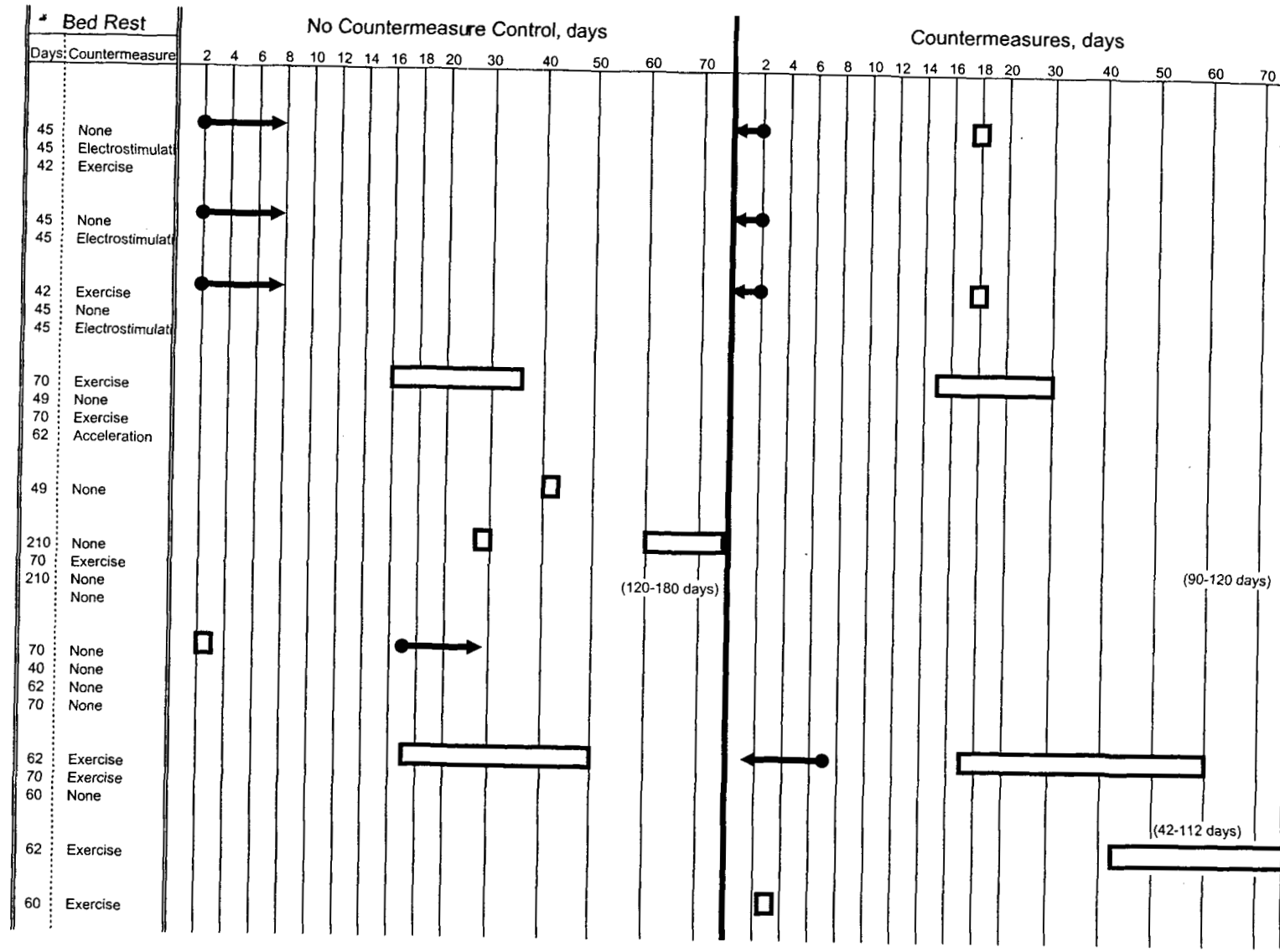
GENERAL BODY FATIGUE (INC)
- 60-75d > Hulley et al. (1971)
- 90-120d > Kalin et al. (1969)
- 120-180d > Donaldson et al. (1969)
- ~28d > Hautman

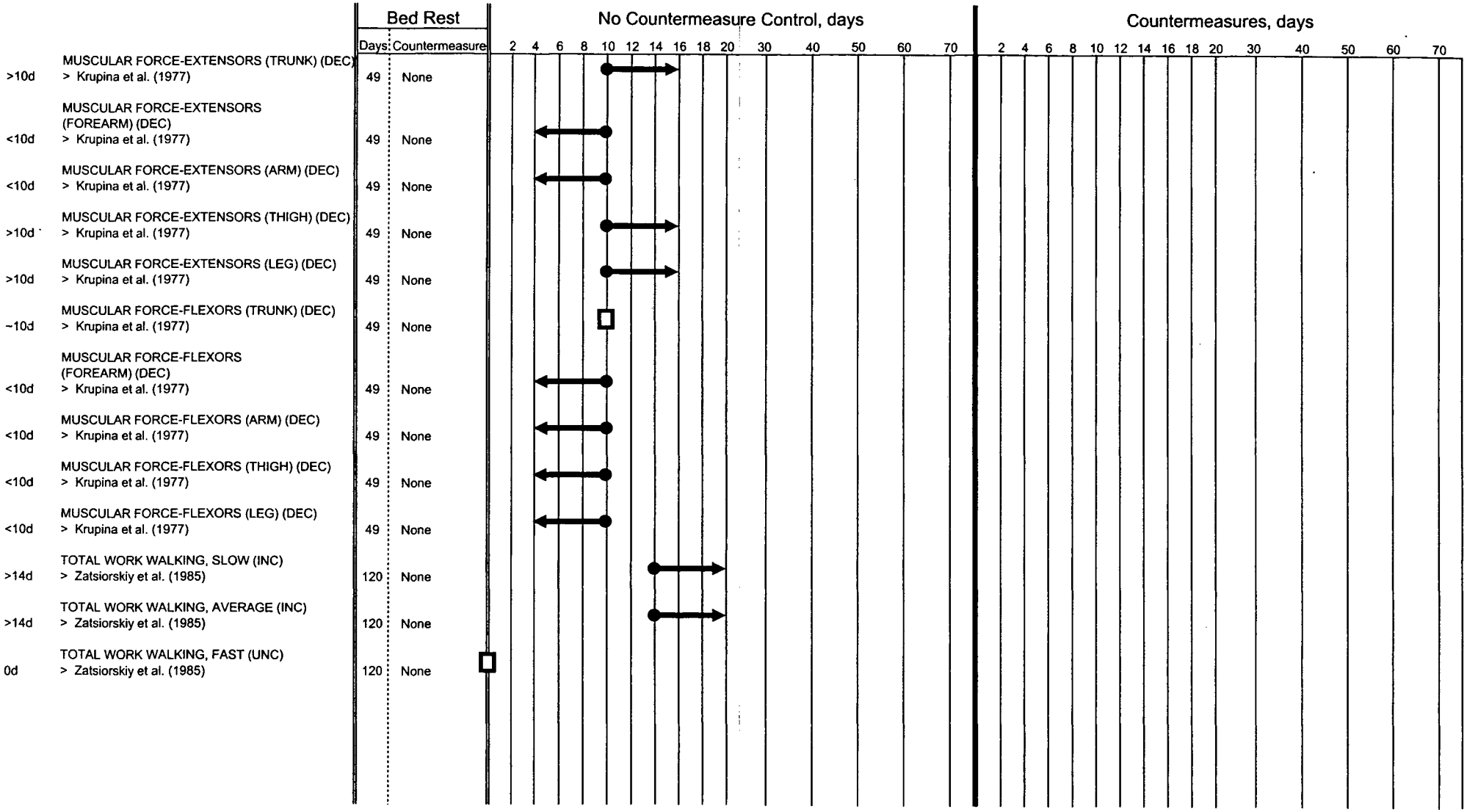
ORTHOSTATIC TOLERANCE (DEC)
- >17d > Beregovkin et al. (1969)
- 2-3d > Korobkov et al. (1968) (Athletes)
- >20d > Mikhaylovskiy et al. (1967b)
- >28d > Pestov et al. (1969)

ACCELERATION TOLERANCE (DEC)
- <7d > +Gx Krupina et al. (1967)
- 17-60d > +Gx Kotovskaya et al. (1969)
- 17-50d > +Gx Kotovskaya et al. (1971)

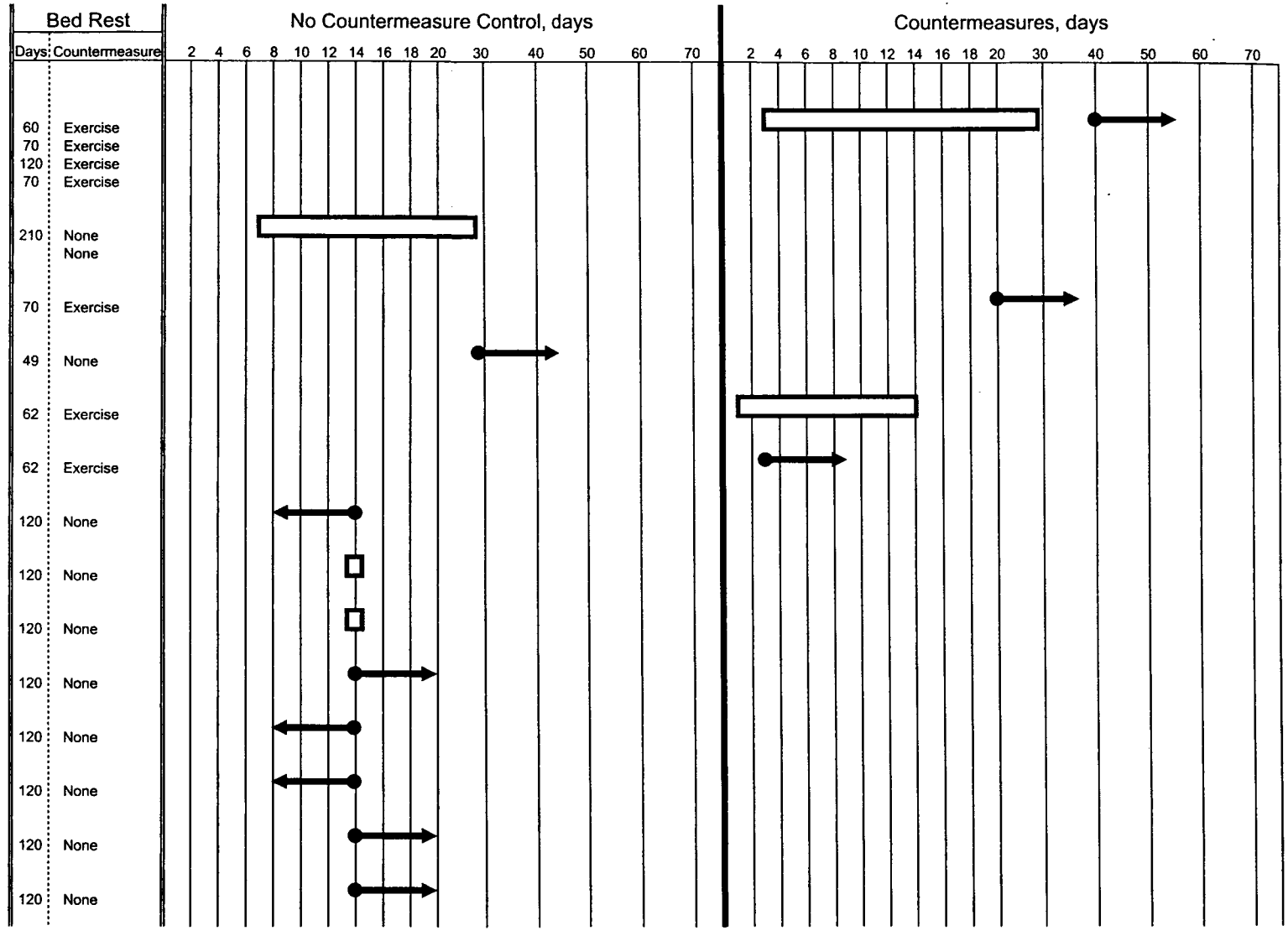
CORIOLIS ACCELERATION TOLERANCE (DEC)
- 42-112d > +Gz Krupina et al. (1967)

HAND GRIP STRENGTH (DEC)
- ~3d > Brannon et al. (1963)

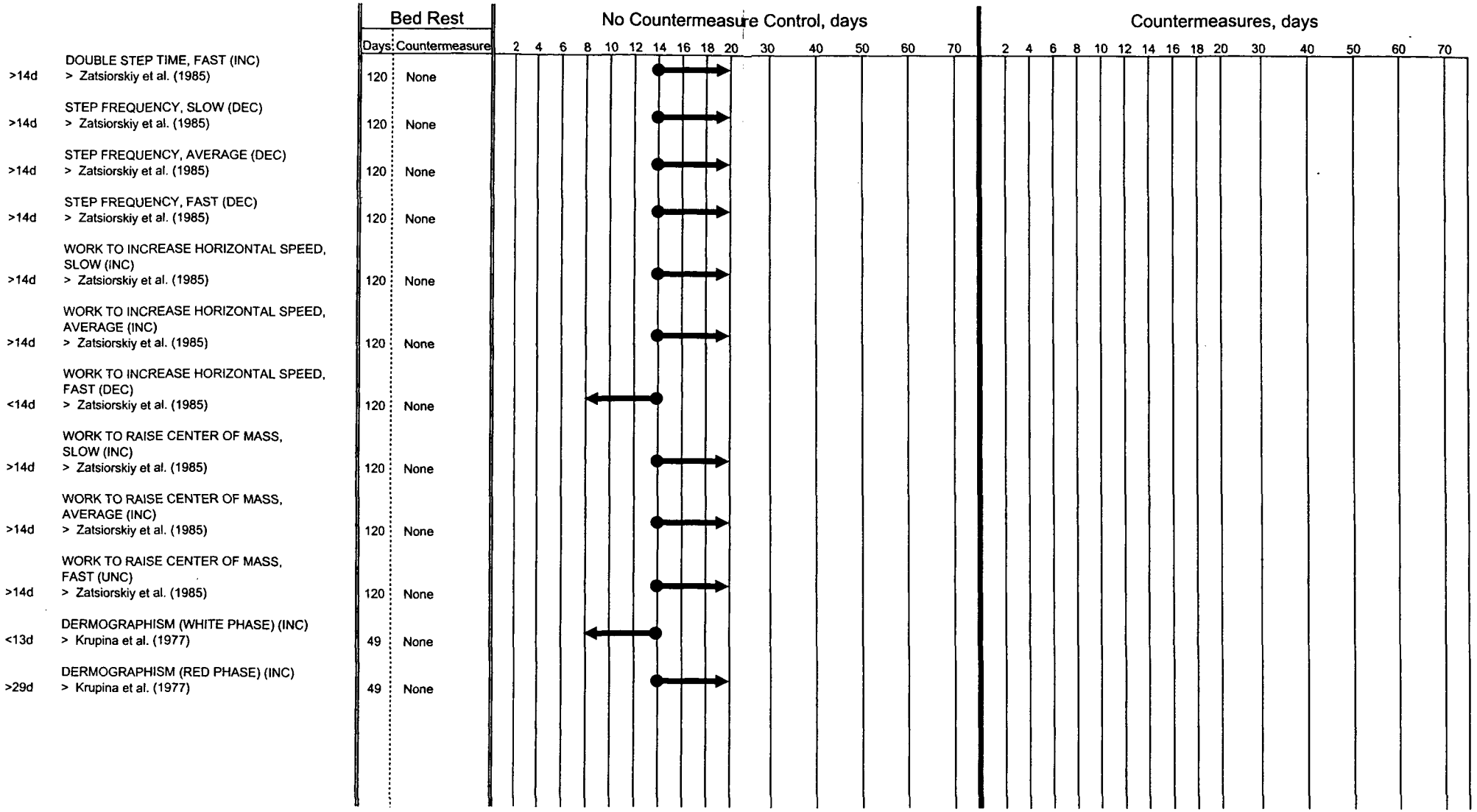



Bed Rest
No Countermeasure Control, days
Countermeasures, days
Days
Countermeasure
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
MUSCULAR FORCE-EXTENSORS (TRUNK) (DEC)
>10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-EXTENSORS (FOREARM) (DEC)
<10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-EXTENSORS (ARM) (DEC)
<10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-EXTENSORS (THIGH) (DEC)
>10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-EXTENSORS (LEG) (DEC)
>10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-FLEXORS (TRUNK) (DEC)
~10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-FLEXORS (FOREARM) (DEC)
<10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-FLEXORS (ARM) (DEC)
<10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-FLEXORS (THIGH) (DEC)
<10d > Krupina et al. (1977) 49 None
MUSCULAR FORCE-FLEXORS (LEG) (DEC)
<10d > Krupina et al. (1977) 49 None
TOTAL WORK WALKING, SLOW (INC)
>14d > Zatsiorskiy et al. (1985) 120 None
TOTAL WORK WALKING, AVERAGE (INC)
>14d > Zatsiorskiy et al. (1985) 120 None
TOTAL WORK WALKING, FAST (UNC)
0d > Zatsiorskiy et al. (1985) 120 None

4. PSYCHOLOGICAL TESTS



		Days	Countermeasure
	BODY STEADINESS (DEC)		
>40d	> Brannon et al. (1963)	60	Exercise
21-28d	> Kalin et al. (1969)	70	Exercise
13-28d	> Purakhin et al. (1972)	120	Exercise
3-28d	> Gurfinkel et al. (1969)	70	Exercise
	FOOT SENSITIVITY (INC)		
21-28d	> Donaldson et al. (1969)	210	None
7-21d	> Hautman		None
	VISUAL FUNCTION (DEC)		
>20d	> Drozdova et al. (1969)	70	Exercise
	VISUAL WHITE SPOT (INC)		
>29d	> Krupina et al. (1977)	49	None
	AUDITORY THRESHOLD (INC)		
1-14d	> Krupina et al. (1967)	62	Exercise
	EEG FREQUENCY SHIFT		
>3d	> Petukhov et al. (1968)	62	Exercise
	WALKING SLOW (DEC)		
<14d	> Zatsiorskiy et al. (1985)	120	None
	WALKING AVERAGE (DEC)		
~14d	> Zatsiorskiy et al. (1985)	120	None
	WALKING FAST (DEC)		
~14d	> Zatsiorskiy et al. (1985)	120	None
	DOUBLE STEP LENGTH, SLOW (INC)		
>14d	> Zatsiorskiy et al. (1985)	120	None
	DOUBLE STEP LENGTH, AVERAGE (UNC)		
<14d	> Zatsiorskiy et al. (1985)	120	None
	DOUBLE STEP LENGTH, FAST (DEC)		
<14d	> Zatsiorskiy et al. (1985)	120	None
	DOUBLE STEP TIME, SLOW (INC)		
>14d	> Zatsiorskiy et al. (1985)	120	None
	DOUBLE STEP TIME, AVERAGE (INC)		
>14d	> Zatsiorskiy et al. (1985)	120	None


Bed Rest
Days
Countermeasure
No Countermeasure Control, days
Countermeasures, days
2 4 6 8 10 12 14 16 18 20 30 40 50 60 70
DOUBLE STEP TIME, FAST (INC)
>14d > Zatsiorskiy et al. (1985) 120 None
STEP FREQUENCY, SLOW (DEC)
>14d > Zatsiorskiy et al. (1985) 120 None
STEP FREQUENCY, AVERAGE (DEC)
>14d > Zatsiorskiy et al. (1985) 120 None
STEP FREQUENCY, FAST (DEC)
>14d > Zatsiorskiy et al. (1985) 120 None
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Recovery data were analyzed from normal healthy test subjects maintained in the horizontal or head-down body position in well-controlled bed rest (BR) studies in which adherence to the well-designed protocol was monitored. Because recovery data were almost always of secondary importance to the data collected during the BR period, there was little consistency in the recovery experimental designs regarding control factors (e.g., diet or exercise), duration, or timing of data collection. Thus, only about half of the BR studies that provided appropriate data were analyzed here. These recovery data were sorted into two groups: those from BR protocols of less than 37 days, and those from protocols greater than 36 days. There was great disparity in the unchanged responses at the end of BR in these two groups. Likewise with the variables that required more than 40 days for recovery; for example, some immune variables required more than 180 days. Knowledge of the recovery process after BR in healthy people should assist rehabilitation workers in differentiating "healthy" BR recovery responses from those of the infirmity of sick or injured patients; this should result in more appropriate and efficient health care.

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